A

COURSE OF LECTURES

ON THE

Steam Engine,

DELIVERED

BEFORE THE MEMBERS

OF THE

LONDON MECHANICS' INSTITUTION.

BY

CHARLES F. PARTINGTON,

OF THE LONDON, RUSSEL, AND SURREY INSTITUTIONS.

TO WHICH IS SUBJOINED,

A Copy of the Rare and Curious Work on Steam Navigation, Originally published by Jonathan Hulls in 1737.

Illustrated by Seventeen Engravings.

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TO THE EDITOR

OF THE

LONDON MECHANICS' REGISTER,

AND THE

Operative Classes

OF

GREAT BRITAIN, THE REAL STRENGTH AND SINEWS

OF A

GREAT COMMERCIAL NATION,

THE PRESENT ACCOUNT OF THE

STEAM ENGINE

IS INSCRIBED BY THE

EDITOR.

The accompanying Lectures are edited from the admirable *Reports* of the *Course* originally published in the *London Mechanics' Register*, in which valuable work much highly interesting scientific matter will be found interspersed. The Editor feels it proper to add, that those readers who wish for further information on the subject, may find it in the new edition of the Lecturer's Historical and Descriptive Account of the Steam Engine.

LECTURES

ON

THE STEAM ENGINE.*

STEAM was employed as a prime mover at a very early period, as its first recorded application to this purpose took place about 2000 years ago, when

* Mr. Partington introduced the important subjects, which he was about to illustrate, by observing, "That as it is an undeniable truth, that the length of our existence bears but a very small proportion to the knowledge which science has to bestow, it is both an useful and an honourable office to give the benefits of long-tried experience, and the results of the most painful labours, in as brief and popular a form as may be consistent with perspicuity and truth. Even to read the history and principles of any branch of science, and all its members are essential portions of an enlightened education, is a work which few possess the time or inclination to effect. Add to this, too, that the perusal of such works as induct us to the study of Natural Philosophy, requires much and careful examination; so that the mind soon flags—our attention soon becomes bewildered—the references which are intended to explain, frequently confound—and for want of actual experiment, the established truths of science, and the wonderful combinations of art, are too frequently unintelligible.

"In this case, then, the excellence of public experimental lectures, such as have been delivered by my colleagues in this Institution, is most perfectly demonstrated. In them, after the seclusion of severe and more uninter-

Hero of Alexandria constructed the apparatus represented in the diagram to which the lecturer in the first instance directed the attention of his auditory.

The annexed diagram is a representation of Hero's apparatus. Water being introduced into the vessel F, heat is applied externally, and the steam passing through the perpendicular pipe E, which is bent at right angles, enters into the globe G. This globe is furnished with two bent tubes, A and D, and turns freely on the pivot at the end of the pipe C on the one side, and on the steam-tight joint at B on the other. The steam rushing from the orifices of the jets A and D produces a rotary motion, which arises

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rupted studies, may the scholar, quitting his sable-lettered page, be equally delighted in his sight and understanding. In them, for one short hour, when the toil of the commercial world is over, and the artisan lays aside his tools, may the merchant and the mechanic meet to learn fresh lessons in their respective occupations. The latter, the thousand treasures which science possess to render his labours valuable, easy, elegant, and lasting; and the former to listen to that connection which all the arts have formed with commerce. How they bring contributions from a thousand sources, to render our merchants like princes, whilst the manufactures of our land, thus perfected, become solid riches, of which the more they are spread abroad, the more they increase our natural wealth,

"And gathering tribute from each distant shore,
In Britain's lap the world's abundance pour."

"Need I add, gentlemen, that it is to the Steam Engine we are mainly indebted for nearly all the advantages that I have thus faintly portrayed? And with that stupendous machine, ere our lectures are completed, I trust to make you perfectly acquainted."

from two causes, viz. the resistance which the atmosphere offers to the steam, and the removal of the internal pressure at the orifices by which the equilibrium is destroyed.*

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* *Water*, when heated under ordinary atmospheric pressure to 212° Fahrenheit, becomes converted into *steam*, in which state it is expanded to about 1800 times its former bulk. Mr. Partington exemplified the formation of steam, by heating some water contained in a glass retort by the flame of a spirit lamp till it boiled. The tube of the retort was soon filled with a white cloud, but this, the lecturer observed, was not the colour of steam as it was produced in the steam engine. Upon boiling the water in a common tea-kettle, the steam which issues from the spout assumes the same clouded appearance, but that which is contained within the kettle is as clear, or clearer, than the purest glass. The reason why the steam appears like a cloud is, that the constitution of its particles is changed when it comes in contact with the colder atmosphere, by which it is partially condensed: but it will be seen by the retort in which the water is boiling, that while the temperature of the steam is preserved at 212°, it is perfectly transparent and invisible in the tube, and that it does not become cloudy till it issues into the atmosphere, where it is condensed by the diminution of its temperature.

It has been stated that water, under ordinary circumstances, is converted into vapour at 212° Fahrenheit, but there are other fluids which may be boiled at a much lower temperature. Mr. Partington applied the flame of the spirit lamp to a vessel containing ether, which was very readily boiled; and he exemplified the conversion of the fluid into vapour, as well as the force with which it expanded, by applying a light to the aperture from which the steam issued, when it instantly ignited, and spouted forth a stream of vivid fire to the distance of several yards. If water had been used instead of ether, it would have required a longer time to boil it, and if mercury were substituted

This may be considered as a high pressure engine, and in the year 1624, De Caus constructed a machine in which high pressure steam was also employed for the purpose of driving up a jet of hot water, in a manner similar to the apparatus now exhibited by the lecturer. This apparatus consisted of a close vessel partly filled with water, and furnished with a small tube passing through the top of the vessel and reaching nearly to the bottom of it. Upon boiling the water by applying the flame of a spirit lamp beneath the vessel, the pressure of the elastic vapour on the surface of the water forced it through the vertical tube, from which it rose in a strong jet. This machine is only applicable to the purpose of raising water, and is very expensive from its great consumption of fuel, as the water must necessarily be kept up to the boiling point to keep the fountain playing. An apparatus of this kind has been employed to illustrate the boiling fountains of Geyser, by introducing a valve into the tube; but some danger is incurred by this experiment, as the choking of the orifice may cause the destruction of the vessel, and occasion some injury to those in its neighbourhood.

The next apparatus in which steam was employed as a prime mover was the invention of Giovanni Branca, an Italian philosopher, and is represented

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for the spirituous fluid, a much more intense heat than that of the small spirit lamp would be necessary to produce ebullition.

as in the diagram, in a work published at Loretto in 1629.

In this figure the bust beneath the head represents the boiler, to which heat is applied till the water is converted into steam, which rushes from the mouth of the negro, and is directed against the vanes of a float wheel. The wheel is driven round by the force of the elastic vapour, and by attaching a pinion to the wheel, it is evident that motion may thus be communicated to machinery. Branca applied it to the purpose of giving motion to a pounding machine. This apparatus is, however, liable to several objections, for the steam is partially condensed during its passage through the air, and undergoes a further condensation on coming in contact with the cold wheel, which it is impossible to keep at the temperature of boiling water without inclosing it. Thus the steam acts with a greatly diminished force, but that, even with these disadvantages, it possesses considerable working power, might be seen by the apparatus on the lecture table.

This apparatus, instead of the picturesque representation of the blackmoor's head, consisted of a hollow brass globe, about six inches in diameter, containing some water, and furnished with a bent tube proceeding from the upper part, and terminating in a narrow aperture. Opposite to the mouth of the tube was placed a float-wheel, and upon heating the water in the globe, the steam rushed from the orifice against the vanes of the wheel, and put it in

rapid revolution. Mr. Partington also shewed, by placing the flame of a lamp in the jet of steam, that an apparatus of this kind might be used as a very convenient blow-pipe.

Passing on to the year 1663, we arrive at the period when the Marquis of Worcester published his "Century of Inventions," in which the Steam Engine is evidently alluded to as one of the discoveries claimed by the Marquis. Hitherto, though steam had been used as a prime mover, its power was little known, but the noble author's application of this agent appears to have been much more effective, and his views will be best explained in his own words. Mr. Partington here read the 68th Article of the Century of Inventions as follows:

"An admirable and most forcible way to drive up water by fire, not by drawing or sucking it upwards, for that must be, as the philosopher calleth it, *infra sphæram activitatis*, which is but at such a distance. But this way hath no bounder, if the vessels be strong enough; for, I have taken a piece of a whole cannon, whereof the end was burst, and filled it three-quarters full, stopping and screwing up the broken end, as also the touchhole; and making a constant fire under it; within twenty-four hours it burst and made a great crack: so that having found a way to make my vessels, so that they are strengthened by the force within them, and the one to fill after the other, have seen the water run like a constant fountain stream, forty feet high; one

vessel of water, rarefied by fire, driveth up forty of cold water; and a man that tends the work is but to turn two cocks, that one vessel of water being consumed, another begins to force and refill with cold water, and so successively, the fire being tended and kept constant, which the self-same person may likewise abundantly perform in the interim between the necessity of turning the said cocks."

This is all the explanation the Marquis has given of his apparatus, for though he intimated his intention of leaving to posterity a full description of it, no further account is on record. He stated his wish that the machine should be buried with him, and perhaps this was the case, for his invention is lost to us, with the exception of the imperfect description contained in his work.*

* We do not know how the Marquis of Worcester condensed his steam, or, indeed, whether he condensed it at all, for it certainly does not require condensation unless it be for raising the water by atmospheric pressure. It is said, that the condensation in the first engines was effected by water on the outside of the vessel; but in Savery's engines it was performed within the vessel. Several of his engines were made with only one steam vessel; and Desaguliers found by experiment, that this kind is considerably better than such as have two, because the action of the steam is rendered more sudden, and the chemical condensation during the process of forcing is less. This excellent philosopher and practical engineer made several other improvements in Savery's engine and its parts, which may be seen in his published works. But the subsequent invention of the Steam Engine with a piston and lever, and the improvements which have been made therein, seem to have greatly retarded the progress of the original simple machine.

Mr. Partington then proceeded to describe the construction of Captain Savery's Steam Engine, of which he published a description in the "Miner's Friend," in the year 1669. This machine, which is here represented, evidently owes its operation in a great measure to atmospheric pressure :—

This apparatus consisted of a boiler O, furnished with a safety valve M, acting by means of a weight W at the end of the lever L. The steam-vessel S, into which the steam was made to pass through the pipe N, was connected with the well C by the suction-pipe H P, and when water was to be raised, the vessel S was filled with steam, which completely expelled the air. The communication with the boiler was then closed by shutting the valve Q, and the steam in the vessel becoming condensed, a vacuous space was formed, into which the water rushed from the well by the pressure of the atmosphere on its surface. The handle R is used to give motion to the double valve I and Q, the former being intended to admit condensing water from the pipe A D, while the latter alternately opens and shuts the steam communication. In this form of the apparatus the inventor was seldom able to raise water more than 30 feet, and when a greater altitude was required, it was affected by the impelling force of the steam. This was accomplished by the ascending pipe A D, which was sometimes carried 60 feet higher than the steam-vessel S. After condensing the steam, and filling the vessel S with water, a new supply of steam

was introduced, which, pressing on the surface of the water, drove it up the pipe D; but it will be evident that this operation must be sometimes very dangerous, as the pressure on the internal surface of the boiler must be in proportion to the height of the column of water raised by the elasticity of the steam.

After the preceding explanation of the large diagram of Captain Savery's engine, to which Mr. Partington referred his hearers, he simplified its operation by boiling a small quantity of water in a glass retort, which was immediately filled with steam and the air expelled. He then immersed the extremity of the neck of the retort in a coloured fluid, and by cooling the vessel, condensed the steam, when the fluid instantly rose into the vacuum by the pressure of the atmosphere, and nearly filled the retort. The value of this experiment was increased by the facility with which it might be performed by any of the members, by heating water in a small flask.

Mr. Partington finally illustrated the principle of Savery's engine on a larger scale, by means of a tube of glass reaching from the upper gallery nearly to the lecture table. The lower extremity of this tube was immersed in a vessel of coloured water, and the assistant in the gallery having expelled the air from the tube, or at least greatly rarefied it, by generating steam and then condensing it in a retort connected with the tube, the coloured fluid began to rise, and continued gradually to ascend till it reached a height of more than 20 feet. This apparatus, observed

Mr. Partington, would form a good *water barometer*, if a perfect vacuum was produced, when the water would continue to rise till the column was in equilibrium with an equal column of atmospheric air without. This experiment will elucidate the application of Capt. Savery's machine to the purpose of raising water from mines.

Dr. Papin, well known for his invention of the digester, improved this form of the engine. Prony, in his *Architecture Hydraulique*, (i. 566,) mentions a work of his, printed at Cassel in 1707, under the title of *Nouvelle Maniere d'elever l'Eau par la Force de Feu*, in which a steam-engine is described which differs from that of Savery, but may well accord with the description of the Marquis of Worcester. From the engraving in his second volume, it appears to have consisted of a spheroidal boiler, a cylindrical steam-vessel, into which was fitted a float or piston, and an air-vessel which received the water from each stroke previous to its being forced by the steam to a greater height. The water flowed through a pipe with a valve opening upwards, whence it passed beneath the piston which floated upon it. The descent of the piston was effected by the steam, and its ascent by the action of the water from the original stock, at which period the steam was suffered to escape into the air by means of a cock, and the communication between the boiler was thus shut off.

The *atmospheric steam-engine* is a machine of vast importance, and is now employed to a very con-

siderable extent. In this powerful apparatus the steam is introduced beneath an air-tight piston moving in a cylinder, and the piston being driven up by the expansive force of the steam, the latter is condensed by means of cold water. A vacuum is thus formed in the cylinder, and the piston consequently descends by the pressure of the atmosphere on its exterior surface. The piston is made air-tight, not by employing *leather*, but by a packing of hemp.

The better to understand this apparatus, we may, however, suppose a very large syringe to be placed in a perpendicular direction, and a piston or plug inserted at the upper end, the usual aperture being supposed to be at the lower extremity. If this last aperture be open, the piston will descend by its own weight, if that exceed the resistance arising from friction. But if we suppose the piston to be supported by a counterweight at the opposite extremity, of a lever, or by any other means. In this case the piston will not descend, unless more weight be added to it. Among the various ways of applying such a weight, there is one which exists in exhausting the air from the internal part of the cylinder beneath the piston. For, if this were done, it is evident that the whole pressure of the atmosphere, which amounts to more than twelve pounds on every inch, will become active upon the upper surface. If the vacuum were to be produced by means of an air-pump, it may easily be conceived, that the labour

of effecting it would be at least equal to that of any work which might be performed by the subsequent descent of the piston. We have seen that, in Savery's engine, the operation of steam is twofold; namely, by the direct pressure from its elasticity, and by the indirect consequence of its condensation, which affords a vacuum. This last is the only principle displayed in Newcomen's engine. In order to produce the vacuum at pleasure, it becomes requisite that various apertures should be formed at the bottom of the cylinder or syringe we have been speaking of: one to communicate steam from a boiler; another to admit a jet of cold water, to condense that steam during the interval in which the communication from the boiler is cut of; a third provided with a pipe called the eduction-pipe, to carry off the condensed steam and injection water; and, lastly, a small lateral aperture or valve, through which the permanently elastic fluid, which cannot descend through the eduction-pipe, may be driven out. This last is called the snifting clack. By these provisions the operation is made to take place as follows: the piston being up, the steam-cock is opened, and steam issues from the boiler, which being less than half the weight of common air, rises to the top and expels the air through the eduction-pipe, of which the lower extremity is covered with a flap valve in a trough of water. When the noise of its escape is heard the steam-cock is shut, and the injection-pipe being opened, throws a stream of cold water against the bottom of

the piston. The steam becomes immediately condensed, and the pressure of the atmosphere forces the piston down into the vacuum. Upon its progress downwards the injection-pipe is closed, and when it has arrived nearly to the bottom of the cylinder, the steam-cock is again opened. The elastic vapour then not only fills the small space between the cylinder and the bottom, but its pressure assists the eduction water to pass off through its pipe, and drives the disengaged steam through the snift valve. In this state, therefore, the steam is somewhat stronger than the atmosphere, and counterpoises its action on the upper surface of the piston, whence the piston itself rises by the action of the counterweight, and regains its original position at the top of the cylinder. A second repetition of the process, namely of shutting off the steam and injecting cold water, causes it again to descend, and in this manner the alternations may be continued without limit.

Mr. Partington now directed the attention of his audience to a large diagram, representing the atmospheric steam engine, the operation of which he minutely described. A correct view of this engine is given in the accompanying engraving. The steam is generated in the boiler B, and is admitted into the cylinder A, when the piston is at the top, as represented in the engraving. D D is a large beam or lever, moving on an axis, and supporting at one extremity the rod E of the steam piston, by means of a chain passing over an arch of wood at

the end of the lever or working beam. The reason for employing this arch will be obvious, if we consider that the distance of the extremity of a common lever from a perpendicular beam supporting the fulcrum is continually varying, and would therefore draw the piston rod out of its vertical direction; but by attaching a flexible chain to part of a circle of wood, of which the fulcrum is the centre, the piston rod is constantly kept at the same distance from the perpendicular beam, and its vertical motion is preserved. The air being expelled by the admission of steam to the cylinder A (which is placed within an exterior cylinder), the communication with the boiler is closed, and a portion of cold water admitted outside the cylinder from the reservoir H, which instantly condenses the steam, and forms a vacuum below the piston, which is then forced to the bottom of the cylinder by the pressure of the atmosphere. To the opposite end of the lever beam the pump-rod is suspended, furnished with a counterpoise F, to elevate the piston-rod after its descent in the cylinder. The piston being thus alternately elevated and depressed, a quantity of water will be raised from the well at every stroke of the engine, in proportion to the force with which the atmosphere presses upon the piston. M is a safety valve, and C a small pipe descending into the water in the boiler, for the purpose of ascertaining the quantity it contains; for if the cock at C is turned while the lower extremity of the pipe is immersed in the water, the

elasticity of the steam will force *water* through the aperture; but if the surface of the water in the boiler is below the end of the pipe, only *steam* will issue when the cock is turned. G G is a tube communicating with the well to supply condensing water to the reservoir H. K and L are pipes for conveying the water formed by the condensation of the steam on the interior and exterior of the cylinder, into the well I.

In this form of the atmospheric engine, two cocks were employed, which it was necessary to open and shut at every working stroke; the one for the purpose of admitting steam from the boiler into the cylinder, and the other to introduce the condensing water from the cistern. This circumstance occasioned much inconvenience, which is stated with some degree of truth to have been obviated by the contrivance of an idle boy, who was employed to open and shut these communications alternately. He observed, that by connecting the two stop-cocks by means of a string, they opened and shut each other, and by adopting this principle, the atmospheric engine was rendered a self-acting machine.

The principal objection to the practical application of this engine is the necessity for cooling the cylinder by the condensing water every time the piston ascends. When water is converted into steam, its pressure is in proportion to the degree of heat applied, but it will be partially condensed, and its effective force diminished by the least diminution of

its temperature. Mr. Partington here boiled some water in a flask, and closing the orifice when the air was expelled by steam, he withdrew the flask from the flame of the spirit lamp till the water ceased to boil. He then plunged it into a vessel of *cold water*, when the water within the flask instantly boiled rapidly. While in this state of ebullition, he removed it from the cold water to the flame of the lamp, and the water immediately ceased to boil. This experiment shews the facility with which steam is condensed by diminishing its temperature, and also proves that water may be boiled with much less heat when the pressure is removed from its surface. Thus when the water in the flask had ceased to boil, upon immersing the vessel in cold water, the steam was condensed, and a partial vacuum being produced, the water again boiled, though its heat was reduced below 212°, because the external pressure was removed. Upon again applying heat to the flask, steam was generated, and the pressure being thus restored, the water ceased to boil.*

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* It may be advisable in this place to give the results of the performance of some old engines, as they are described by Mr. Farey. The same engines were afterwards improved by Mr. Smeaton. The engine at Long Benton colliery, which was considered as one of the best in the neighbourhood of Newcastle, was tried by Mr. Smeaton in 1772; it was of the following dimensions: cylinder 52 inches diameter, stroke 7 feet. The pump was 12 inches diameter, and drew the water 61 fathoms high; and also an injection pump 8 inches diameter, and 5 feet 7½ inches stroke, which raised water 58 feet. This engine consumed 8 bolls (of

The annexed diagram represents a compact and ingenious piece of apparatus, contrived for the pur-

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2 cwt. 1 qr. 21½ lbs. each) of coals, such as are generally used for engines, in two hours and two minutes, when working at the rate of from 7½ to 8 strokes per minute, or 7¾ per minute at the medium.

The computations from these data are first to ascertain the real weight of water in the pumps; the main pump being 12 inches diameter, and the injection pump 8, the proportion of the areas of the two will be as the squares of their diameters, and their load in proportion to their height of column; therefore, as 144 : 64 : : 58 feet high : 25.7 feet; that is, the whole load of the injection-pump will be equal to 25.7 feet of the main column of 12 inches diameter; but this is, provided that the length of the stroke was the same in both.

To reduce them to one, say as a 7 feet stroke, or 84 inches : 67.5½ inches : : 25.7 feet : 20.7 feet of the column of the main pumps, say 21 feet.

Hence, the whole load consists of the main column of 12 inches diameter, and 61 fathoms, or 366 feet, and the injection-pump equal to 21 feet thereof, 366+21 feet=387 feet.

To obtain what Mr. Smeaton calls the great product, by which the powers of different engines can be compared, multiply the square of the pump's diameter, 144 inches × 387 feet lift=55728, which multiplied by a 7 feet stroke= 390096, and again by 7.75 strokes per minute=3023244, the whole product or effect of the engine, without regard to coals, or without any allowance for the weight of the pump-rods, and the counterpoise of the engine.

The quantity of coals was 2 cwt. 1 qr. 21½ lbs.=273½ lbs. × 8 bolls=2188 lbs, which divided by 88 lbs., the weight of a London bushel, gives 24.86 bushels consumed in the whole time of the experiment, viz. two hours and two minutes, or 122 minutes.

To find the coals for one hour's work, say as 122 minutes : 60 minutes : : 24.86 bushels : 12.22 bushels per hour.

pose of illustrating in a simple and perspicuous manner, the operation of the common atmospheric steam

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Lastly, the whole product 3023244, divided by 12.22, gives 247401 for the product or effect of one bushel of coals per hour.

This engine was rebuilt according to Mr. Smeaton's plan, with the same cylinder of 52 inches, and 7 feet stroke, but the pumps were enlarged to 12.2 inches diameter, and lifted in two columns, each 24 fathoms 4 feet high. The injection-pipe was 7 inches diameter, 5 feet 6 inches stroke, and lifted 70 feet 7 inches high.

In 1774, Mr. Smeaton tried the experiment, and found that when this new engine was working at the rate of twelve strokes per minute, 2 cwt. 1 qr. 16 lbs. of the common engine coals supplied it 22 minutes.

From this he made a similar computation to those for the former engine. Square of 12.2 inches, the diameter of the main pumps 148.84; square of 7 inches the diameter of injection-pump 49; its lift 70½ feet. Then say as 148.84 : 49 :: 70½ : 23.21 feet of the main column, if the lengths of the strokes were equal; but as they are not, say as the long stroke 84 inches : 66 inches :: 23.21 feet : 18.2; therefore the load of the injection-pump is equal to the load of 18.2 feet of height of the main column.

The total load then is equal to a barrel 12.2 inches diameter, twice 24 fathoms 4 feet, or 296 feet+18 feet, viz. 314 feet of light.

To obtain the great product, multiply the square of the pump's diameter, 148.84 by 314 feet; the height lifted=46735.76, which multiplied by 7 feet stroke=327150.32; and again by 12 strokes per minute=3925803.84, the whole product or effect of the engine, without regard to coals, or without allowance for the weight of the pump-rod, nearly 3 tons, and the counterweight of the engine.

For the quantity of coals, 2 cwt. 1 qr. 16lbs., or 268 lbs., divide it by 88 lbs., the weight of a London bushel, and it makes 3.05 bushels consumed in 22 minutes, the time

engine. In this convenient little machine, the glass tube and bulb *b* is supported by a handle, and fur-

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of the experiment; therefore say, as 22 minutes : 60 minutes :: 3.05 : 8.32 bushels per hour.

Lastly, the whole product 3925803.84, divided by 8.32, gives 471851 for the product, or effect of one bushel of coals per hour. Therefore the effect of this new engine, compared with the former engine, is as 471851 to 247401.

To this computation, which is chiefly comparative between the two engines, we may add the following, to shew the pressure upon each square inch of the piston. The area of the 52 inch cylinder is $52 \times 52 = 2704 \times .7854 = 2123$ square inches.

The weight of the column of water in the pumps, 12.2 inches diameter, will be about 50.9 lbs. weight for each foot in height. For $12.2 \times 12.2 = 148.84 \times .7854 = 116.8$, the square inches in the area of the pump. Now, a cubic foot of water weighs $62\frac{1}{2}$ lbs. nearly, therefore divide 62.5 lbs. by 144, the square inches in a square foot, and it will give .434 lbs, which is the weight of a column of water one inch base and one foot high. Multiply $116.8 \times .434 = 50.7$ lbs., the weight of the column of water in the pumps a foot high; and this multiplied by 314 feet, the whole lift equals 15919 lbs., the total weight of water. Divide this number by 2123, the number of square inches in the surface of the piston, and it will give 7.48 lbs. for the pressure upon each square inch, or $7\frac{1}{2}$ very nearly.

Another method of readily finding the pressure per square inch in the piston is thus: as the square of the diameter of the cylinder ($52 \times 52 =$) 2704 is to the square of the diameter of the pump ($12.2 \times 12.2 =$) 148.84, so is the height which the pump lifts, 314 feet, to 17.24, the height of a column of water, which, if it rested on the piston, would balance the water in the pump. Then multiply 17.24 feet by .434 lbs., the weight of an inch square of water one foot high, and the result is 7.48 lbs. for the pressure per square inch, the same as before.

Since Mr. Watt introduced his improved engines, it has been customary to compare their effects by the number of

nished with a piston, of which the rod *a* is hollow, and closed at the top by a screw *c*. A portion of

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pounds of water which they can raise to one foot high by the consumption of a bushel of coals, without regarding the time in which it is expended. To reduce these two engines to that standard, we must say the first engine consumed 24.86 bushels in 122 minutes; therefore as 24.86 bushels : 122 minutes :: 1 bushel : 49 minutes; that is, one bushel will last 49 minutes. At every stroke, the pump draws up a cylinder of water, 12 inches diameter and 7 feet long, 387 feet high. This cylinder of water will weigh 343 lbs.; for $12 \times 12 = 144 \div .7854 = 113$ inches, the area of the pump. This, multiplied by .434 lbs., the weight of a column one inch square, and one foot high, will be 49 lbs.; and again, multiply by 7 feet for the length, will equal 343 lbs.

The quantity of coals consumed in the first experiment was 24.86 bushels: the experiment lasted 122 minutes, during which time the engine, working at 7¾ strokes per minute, made 945 strokes; then say, as 24.86 bushels : 945 strokes :: 1 bushel : 38; therefore the engine makes 38 strokes for every bushel of coals which it consumes.

At every stroke the engine raises 343 lbs. of water 387 feet. Multiply 343 by 38, the number of strokes, and it gives 13034 lbs., lifted 387 feet by each bushel of coals. Lastly, $13034 \times 387 = 5,044,158$ lbs. of water raised one foot high with a bushel of coals.

The new engine consumed 3.05 bushels in 22 minutes, during which time it worked 12 strokes per minute; it is, therefore, 264 strokes: then say, as 3.05 bushels : 264 strokes :: 1 bushel : 86.5, the number of strokes which the engine will make for each bushel it consumes.

At every stroke the engine raises a cylinder of water, 12.2 inches diameter, 7 feet long, and weighing 354.8 lbs., 314 feet high. Multiply this 354.8 lbs. by the 86.5 strokes which the engine makes for each bushel of coals, and we have 30690, the number of pounds of water lifted 314 feet by each bushel of coals. And, lastly, 30690 lbs. $\times$ 314 feet $= 9,636,660$ lbs. of water lifted one foot high with each bushel of coals.

water is introduced into the bulb *b*, and being heated over the spirit lamp *d*, steam is generated, which expels the air through the hollow rod, and elevates the piston. The screw *c* is then closed, and the apparatus is removed from the lamp, when the steam becomes condensed, and a partial vacuum being produced, the piston descends by the pressure of the atmosphere. Upon placing it again over the lamp, more steam is generated, and thus by alternately heating and cooling the apparatus, a succession of working strokes is produced, and the operation of the atmospheric engine is familiarly explained.

Of those who have contributed to the improvement of this vast machine, beyond all others must be ranked James Watt, who was originally a mathematical instrument maker in the city of Glasgow. In 1765, he was employed to repair the model of Newcomen's engine, belonging to the university of that place; and while examining this imperfect apparatus, he observed the immense loss of steam occasioned by its admission to the cylinder, just cooled for condensation. He found, that a certain number of cubic inches of steam, generated in the boiler, did not operate as they ought in producing a vacuum. In fact, he ascertained by experiments, that one half of the steam of the boiler was lost by its being condensed in the cylinder previously cooled.

He therefore resorted to several different contrivances in order to prevent this condensation. He first made a wooden bottom to the piston, and then made the cylinder wholly of wood. He afterwards

inclosed it with a packing of hemp, to prevent the escape of heat by radiation, and finally introduced the important improvement of *condensing the steam in a separate vessel,* by which means the cylinder was constantly preserved at the boiling temperature. His earliest model is constructed upon this admirable principle, in the practical developement of which it is stated he received considerable assistance from the celebrated Dr. Black, whose discoveries on the subject of heat then excited the general attention of the scientific world. The first improvement then made by Watt consisted of the addition of a condensing cylinder, into which the steam, after raising the piston, was allowed to pass, by opening a valve, where it condensed without lowering the temperature of the working cylinder. The next great improvement he made was that of making the steam itself depress the piston, instead of the pressure of the atmosphere. This was effected by admitting the steam both above and below the piston, in a manner which may be understood by an examination of the following diagram, which is an exact copy of that used by the Lecturer.

When the piston is merely pressed down by the weight of the atmosphere, it is obvious that the pressure cannot be greater than about 15lbs. to the square inch; but by admitting steam *above the piston,* and thus effecting its depression independent of atmospheric pressure, as in the above diagram, the force with which it is driven down can be increased to an almost unlimited extent.

The cylinder A is furnished with a steam-tight

piston, the rod of which is connected with the working beam. This cylinder, instead of being open at the top, like that in Newcomen's engine, is air-tight. The steam is admitted from the boiler through a pipe, of which the orifice is seen at B. Below this opening is situated the throttle-valve *c*, which regulates the quantity of steam admitted through the steam-pipe, by closing or opening in proportion to the divergency of the governor, with which it is connected, in a manner we shall hereafter describe. The steam passes through the box D D, and enters the cylinder either above or below the piston, according to the situation of the *sliding valve*, or bridge *e*, contained in the box, which being elevated or depressed by the motion of the toothed arch, working into the teeth of the valve, alternately opens and closes the apertures which communicate with the upper and lower parts of the cylinder. In the figure, the lower aperture P is open to the steam box, and the steam is entering *beneath the piston*, in the direction shewn by the arrow, and at the same time a communication is formed from the upper part of the cylinder through the aperture *m*, to the pipe through which the steam passes into the condenser. Neither this nor the box D D, in the plan which our engraver copied, is so well defined as we could wish, but a little attention will make the mode of working to be understood. When the piston has reached the top of the cylinder, the direction of the sliding-valve is changed, so that the pipe *m* opens into the steam-box, and the elas-

tic vapour is admitted *above the piston*, while the aperture P is placed in communication with the condenser, into which the steam passes from the lower part of the cylinder during the descent of the piston. By this admirable contrivance, the upper and lower parts of the cylinder were alternately made to communicate with the steam-box and the condenser, and the piston being both elevated and depressed by the power of steam alone, the machine, in the hands of Mr. Watt, became a real STEAM ENGINE.*

* All these improvements were secured to Mr. Watt by right of Patent, notices of which are subjoined.

Patent, 25th October, 1781.—"For certain new methods of applying the vibrating or reciprocatory motion of steam or fire-engines to produce a continued rotative or circular motion round an axis or centre, and thereby to give motion to the wheels of mills, or other machines."

The specification, dated 13th February, 1782, contains a description of five different contrivances of rotative motions.

Patent, 12th March, 1782.—"For certain new improvements upon steam or fire-engines for raising water, and other mechanical purposes, and certain new pieces of mechanism applicable to the same."

The specification, dated 3rd July, 1782, contains, first, the expansive steam engine, with six different contrivances for equalizing the power; second, the double-power steam engine, in which the steam is alternately applied to press on each side of the piston, while a vacuum is formed on the other; third, a new compound engine, or method of connecting together the cylinders and condensers of two or more distinct engines, so as to make the steam which has been employed to press on the piston of the first, act expansively upon the piston of the second, &c., and thus derive an additional power to act either alternately or conjointly with that of the first cylinder; fourth, the applica-

Another contrivance, frequently employed in double-acting engines, for the purpose of conveying

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tion of toothed racks and sectors to the ends of the piston or pump-rods, and to the arches of the working-beams, instead of chains; fifth, a new reciprocating semi-rotative engine, and a new rotative engine or steam-wheel.

Patent, 28th April, 1784.—"For certain new improvements upon fire and steam engines, and upon machines worked or moved by the same."

The specification, dated the 24th August, 1784, describes, first, a new rotative engine, in which the steam-vessel turns upon a pivot, and is placed in a dense fluid, the resistance of which to the action of the steam causes the rotative motion; second, methods of causing the piston-rods, pump-rods, and other parts of engines, to move in perpendicular or other straight lines, and to enable the engine to act upon the working-beams both in pushing and pulling; this is now called the parallel motion, and three varieties are described: third, improved methods of applying the steam-engine to work-pumps, or other alternating machinery, by making the rods balance each other; fourth, a new method of applying the power of steam-engines to move mills, which have many wheels required to move round in concert; fifth, a simplified method of applying the power of steam-engines to the working of heavy hammers or stampers; sixth, a new construction and mode of opening the valves, and an improved working gear; seventh, a portable steam-engine and machinery for moving wheel carriages.

Patent, in 1785.—"For certain newly improved methods of constructing furnaces, or fire-places for heating, boiling, or evaporating of water, and other liquids, which are applicable to steam-engines and other purposes; and also for heating, melting, and smelting of metals and their ores, whereby greater effects are produced from the fuel, and the smoke is in a great measure prevented or consumed."

The specification is dated the 14th June, 1785,

The Act of Parliament, extending Mr. Watt's exclusive privilege for the improvements secured to him by his first

the steam alternately above and below the piston was shewn by a second drawing, to which we may now refer.

In this diagram, K represents the passage leading to the upper part of the cylinder, and a communication is now open with the steam-chamber by the elevation of the upper valve *g*. After this valve has admitted the steam into the cylinder, it is closed, and the lower valve *h* being raised at the same time, a communication is opened between the upper part of the cylinder and the condenser, into which the steam, previously introduced above the piston, is driven during its ascent. The rod, by which the lower valve is moved, passes through the upper one, and the alternate elevation and depression of both is effected by the apparatus L M, which communicate with the working beam of the engine. Another steam chamber, with a similar double valve, is connected with the bottom of the cylinder, for the purpose of introducing the steam beneath the piston, and afterwards conveying it into the condenser.

The first motion of the steam engine is obviously in *right lines*, and this is changed into a *rotatory motion*

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patent, expired in 1800, at which period he retired from business, having, for some years before, ceased to take an active part. Previous to that time, Messrs. Boulton and Watt, juniors, had been received into the partnership, and had erected extensive works, with improved machinery, for the manufacture of steam-engines; and, since the death of Mr. Boulton, the concern has been carried on by them, in conjunction with Mr. Southern and Mr. Murdock.

by means of the crank and fly-wheel.* The fly-wheel acts as a reservoir of power, but adds none; on the contrary, it employs some portion of the power of the engine to give it motion. In the construction of fly-wheels it is necessary that resistance to the air should be, as much as possible, avoided. Another circumstance to be particularly attended to in the construction of fly-wheels, is that they should be sufficiently strong to prevent their flying asunder by their centrifugal force. A want of precaution in this particular had occasioned the loss of several lives, and the lecturer had himself seen a cast iron fly-wheel, of which one quadrant flew off, and materially injured a wall in its neighbourhood.

* Mr. Watt, when speaking of this part of the engine, says, " Among the many schemes which passed through my mind, none appeared so likely to answer the purpose as the application of the crank, in the manner of a common turning lathe (an invention of great merit, of which the humble inventor and even its æra are unknown); but as the rotative motion is produced in that machine by the impulse given to the crank in the descent of the foot only, and is continued in its ascent by the momentum of the wheel, which here acts as a fly; and being unwilling to load my engine with a fly heavy enough to continue the motion during the ascent of the piston (and even were a counterweight employed to act, during that ascent, of a fly heavy enough to equalize the motion), I proposed to employ two engines, acting upon two cranks, fixed on the same axis at an angle of 120 degrees to one another, and a weight placed on the circumference of the fly at the same angle to each of the cranks, by which means a motion might be rendered nearly equal, and a very light fly would only be requisite.

From what has been stated, it will be evident that the use of the fly-wheel is to equalize the motion communicated by the engine, which being in right lines, would stop for a moment between each stroke of the piston, if not carried on by means of the fly and crank. Flys that present a broad surface to the atmosphere are sometimes used to check motion, which would otherwise be too rapid. They are used for that purpose in musical instruments, and are so ingeniously contrived, as to change their position like the balls in the governor of a steam engine.

The *air-pump* is a very important part of the engine. It is employed to draw off the air which is extricated from the cold water continually admitted, entering the condenser. The water which is employed to reduce the temperature of the steam must also be afterwards withdrawn from the vacuous vessel, and this is effected by the same apparatus which performs the double office of air and hot water pump. Attempts have frequently been made to avoid the use of the air-pump, which takes up a considerable portion of the power of an engine. A water barometer, adapted to the condenser, has been sometimes adopted; and a fall of water has been made to pass over the upper edges and down the orifice of a tube, forcing the air before it. The upper end of this tube communicates with the eduction-pipe, and is said to support a vacuum of considerable rarity.

The contrivance by which Mr. Watt regulated the speed of the engine, and which he called the

Governor, is perhaps one of the most ingenious, and at the same time simple, mechanical inventions.

The two balls *i i* are supported by the bent levers *h e g* and *f e d,* which are attached to a vertical rod *a b,* turning on pivots at its extremities, and put in revolution by a hand passing round the pulley *c.* The upper ends *d* and *g* of the levers are connected by the links *k k* with the sliding piece *m,* which moves freely on the spindle *a b.* When the balls *i i* are in contact with the spindle, the slide *m* is at its greatest height on the rod; but when the balls diverge from the rod, as at *o o,* by the centrifugal force, the slider is depressed, and the extremity of the lever *l* moving upon a fixed pivot *n,* is proportionably elevated. This lever, being connected with the throttle-valve of the steam engine, closes or opens it in proportion to the centrifugal force with which the balls diverge from the centre. Thus we find, that the same power which regulates the motions of the planets, and by preventing them from flying beyond their prescribed orbits, preserves the harmony of the great frame of nature, is applied, by a simple piece of mechanism, to regulate the operation of the powerful agent by which the steam engine is moved.*

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* It may be proper to state, that the centrifugal ball, or *governor,* was first employed by Mr. Bunce, and formed part of a model of an improved crane presented by that gentlemen to the Society for the Encouragement of Arts. Mr. Bunce says, "My design is, instead of a pair of

By such admirable contrivances, the steam engine, to use the words of Mr. Jeffray, in his eloquent memoir of Watt, "has become a thing stupendous alike for its force and flexibility, for the prodigious power which it can exert, and the ease, precision, and ductility with which it can be varied, distributed, and applied. The trunk of an elephant, that can pick up a pin, or rend an oak, is as nothing to it. It can engrave a seal, and crush masses of obdurate metals before it; draw out, without breaking, a thread as fine as gossamer, and lift up a ship of war like a bauble in the air. It can embroider muslin, and forge anchors; cut steel into ribbons, and impel loaded vessels against the fury of the wind and waves."

The necessity for keeping the *piston* perfectly *air-tight*, has given rise to various contrivances for effecting this desirable object. This has been accomplished with tolerable accuracy by means of a packing of hemp placed in a circular groove at the circumference of the piston, and pressed down by screws working through a plate placed above the piston. This packing, by continual working, ceases to fit, and much time and steam are lost in removing the cap of the cylinder to re-adjust the packing by tightening the screws. Two improvements on the piston have been introduced for the purpose of ob-

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bellows, to have a ball so connected to a small horizontal wheel, that when the machine moves too fast, it may, by its centrifugal force, throw a stop upon the wheel."

viating this disadvantage, for an illustration of which Mr. Partington referred to two large diagrams, which are correctly copied in the annexed engravings :—

In this modification of the piston, each of the screws is furnished with a toothed wheel *c c*, and these are all connected together by a central wheel *d*, turning loose upon the piston-rod. The head of one of these screws projects through the cap of the cylinder; and it is evident from the figure, that whenever it is necessary to compress the packing beneath the plate, the object is accomplished by turning the head of the projecting screw, which necessarily communicates a similar motion to the rest, and of course turns all the screws at once.

The next improvement is that of Mr. Barton, which is shewn in the accompanying diagram, together with a piston on the usual construction :—

In the first of these figures, the screws F F, acting upon the plate G G, are made to compress the packing H H; the piston rod K being firmly attached by the nut M. In the second figure, which represents Barton's piston, the packing is dispensed with, and the flexible springs T T T, pressing forcibly against the wedges S S S, expand the plates R R R, and preserve the piston air-tight.

The *boiler*, in which steam is generated, is of too much importance to pass unnoticed. The accompanying diagram will serve to illustrate its arrangement. Its connection with the engine will be examined with reference to another engraving.

A represents the interior of the steam boiler. D is a stone float suspended by the wire E to one arm of a lever F, and is so counterpoised by the opposite extremity of the lever, that it always remains at the surface of the water in the boiler; its specific gravity, which would otherwise cause it to sink in the water, being diminished by its connection with the lever. B and C are two pipes communicating with the interior of the boiler, the lower extremity of the former being immersed in the water, and that of the latter terminating at some distance above its surface. The small pipe K is employed to supply the water admitted by the operation of the stone float D, and which, descending by the pipe G, is seen to enter the boiler. H is the steam-pipe, through which the steam passes into the cylinder, and I is a man-hole, to enable a person to enter the boiler for the purpose of cleaning it, and removing the stony concretions deposited by the water.*

* With reference to the quantity of water in a boiler, the principal question, exclusive of the saving of heat, is to determine how far the depth or shallowness of the water in the boiler may influence the production of steam.

If the parts of a mass of water could preserve the same relative positions during the application of heat, and this heat were applied at the bottom under a depth of six feet, it would depend upon the conducting power of the fluid whether the upper or lower parts should give off the greatest quantity of steam in a given time. If the lower parts were to afford the greatest product, this would be done under a greater pressure and at a higher temperature; so that it would become an object of experimental research, whether such steam, by giving out heat to the superincum-

The *safety-valve* is of the greatest importance in the operation of steam engines. The steelyard safety-valve employed by Savery is of very simple construction, and as it operates by means of a balance weight attached to one arm of a lever, the resistance it offers to the expansive force of the steam depends upon the distance at which the weight is placed from the fulcrum. It has, however, been found necessary to render the safety-valve still more secure, by enclosing it in a case, so as to render it inaccessible to the person who has the care of the engine; for upon one occasion, when an accident occurred by the bursting of a boiler, it was found that the attendant was actually sitting upon the safety-valve, and thus loading it with his own weight, in addition to its ordinary pressure. Most persons

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bent water through which it must rise, and rendering a portion of it elastic, might not be as effectual in its ultimate operations, as if the heat had been employed upon a shallower mass. But the fact is, that the parts of fluids do not preserve their relative situation during the application of heat: the water in the boiler will expand and rise with rapidity, as it acquires heat, and in all probability (for in this case also we are in want of facts), will give off a much larger portion of steam while it circulates near the upper surface, and is losing its elevated temperature, than while it glides along the bottom in the act of receiving heat. From this view of the subject, though we are disposed on the whole to conclude, that the shallower mass of water may, in many respects, deserve the preference, yet it may be doubted whether the difference arising from mere pressure be an object of any considerable importance.

have no doubt seen the operation of a little toy called a candle-cracker, which will burst with a considerable explosion when heated, and shatter the candle in which it is placed; and if such an effect is produced by the expansive force of the steam generated by two or three drops of heated water, what, said the lecturer, must be the consequence resulting from the explosion of a large boiler, containing several hundred cubic feet, when the vent provided by the safety valve becomes choked.

The double acting engine, employed by Mr. Partington in this stage of his course, was of the most perfect construction; and as we cannot transfer to our pages the beautiful model referred to by the lecturer, it will be necessary to employ an engraved view for its illustration. Fig. 1 (Frontispiece) represents a general view of the apparatus, *a* being the pipe by which steam is supplied from the boiler. The cylinder *b* is furnished with a piston and rod *c*, which is attached by means of the parallel motion to one extremity of the great working beam or lever *d*. At the other end of the same lever is the rod *f*, united at the crank *g*, and this gives motion to the fly-wheel, which is intended as a magazine or reservoir of power. A sucking or atmospheric pump is seen at *i*, which is used to supply the condenser with cold water from a well or cistern beneath. The air-pump is connected, by means of a rod *m*, with the working beam *d*, and the condenser *n* should be surrounded

by cold water, continually pumped into the vessel in which it is placed.*

A portion of the hot water is drawn off by the pump *l* to supply the boiler. A *barometer-guage* is attached to the central pillar which supports the upper frame of the engine, and is connected with the condenser *n* by the pipe *r*. A steam pressure guage descending at *o*, and filled with mercury, shews the elastic force exerted by the steam then operating on the engine. A slight reference to these two tubes will give the working power of the apparatus; for if we suppose the vacuum within the condenser so perfect as to draw up a column of mercury within the tube as high as the common barometer stands, and at the same time the steam guage *o* gives a pressure of about fifteen pounds on each inch, we shall have two atmospheres, or about thirty pounds of effective power on the same surface of the piston. The eduction-pipe *t* is furnished with the ascending rod *s*, which is moved by a handle and regulating index above, so that any required quantity of cold water may be admitted into the condenser.

The second figure on the same plate will convey a sufficient idea of the boiler attached to the engine,

* It is here worthy of remark, that this cistern is seldom adequately supplied with cold water to ensure the condensation of steam: and the lecturer remarked, "that he had frequently seen instances in which the misnamed cold-water cistern contained water at a temperature much beyond what the hand could bear, without the most painful scalding sensation."

to which we have already alluded. The steam-pipe *a* is furnished with a throttle-valve *g*, which is employed to limit the supply of steam to the engine, a connecting handle being placed at *b*, by which the communication with the engine may be entirely cut off if required. The two guage pipes placed at *f* are intended, as we have already explained, to shew the height of water in the boiler. A very convenient safety-valve is placed at *m*, consisting of a steam box and conical valve, so that when the valve is raised by the elastic force of the vapour beneath, it is allowed to escape, by means of the pipe *n*, into the chimney. The sliding plate *e* is a very important appendage to the boiler. It is connected by means of the chain *d* passing over friction rollers with the conical valve *o*, so that when an excess of steam is generated within the boiler, the plate descends, and the fire is damped by the diminished draft that results. The stone-float apparatus may now be described: it consists of a lever *c*, to which is attached a wire and a small block of stone, the stone being shewn by the dotted figure within the boiler. To the other extremity of the same lever is suspended a valve, which also acts as a counter weight; and when the water sinks within the boiler, the stone descends and the valve is raised, which admits a new supply of water from the cistern above. The bent tube *h* performs the double office of safety valve and guage, to shew the pressure of steam within the boiler, the latter object being effected by a reference to the raised

column of mercury placed within its bore, and the safety of the boiler is ensured by the facility with which the mercury would be blown from the tube, should the steam acquire a dangerous degree of elasticity by the undue application of fuel beneath.

When the tube is of glass, this difference of level may be seen and measured on a scale; but when an iron tube is used, a small light wooden rod is made to float on the surface of the mercury in the open leg, and point out the height on a scale of inches fixed above the tube. But in this case the divisions, which are numbered for inches, must be only half inches; because, as the mercury descends in one leg as much as it rises in the other, the scale reads double, to shew the difference of level.

Steam engines without beams have been made in a variety of forms. The simplest of all is to connect the piston rod at once with the connecting rod, and to place the crank over the centre of the cylinder: the piston rod must be guided by a parallel motion, or by sliders. The objection to this is, that the fly-wheel becomes elevated to too great a height for the communication of its motion, except in very particular circumstances, without shortening the connecting rod, which occasions the irregularity of the action of the crank to be very considerable. In the best form of the engine the connecting rod is made about six times the length of the crank, or three times the stroke of the engine, as a shorter cannot be made to work well. There is also a difficulty in balancing

the weight of the piston rod, connecting rod, and crank, and in giving motion to the air-pump. The balance-weight is usually placed on the rim of the fly-wheel, and the air-pump is either worked by a second smaller crank upon the axis of the fly-wheel, or by a shorter beam.

Engines of this kind are frequently placed with the cylinder horizontally, and for small engines this answers very well; but in large ones, the weight of the piston acting always at one side, wears the cylinder irregularly. Mr. Murray included this plan in his patent of 1799, which we have before mentioned, for producing the rotatory motion without a crank, and he proposed to place rollers beneath the piston to bear it up.

The employment of *high pressure steam*, or that elastic vapour which is generated by the application of heat to water in a close vessel, has now become very general in those situations in which economy in the consumption of fuel, or a deficiency in the supply of cold water, renders the ordinary condensing engine unavailing. Indeed, it has been long known, that the extent of the pressure increases in a greater ratio than the expenditure of heat, which has been an inducement to many to attempt to use steam at excessive pressures. The pressures generally allowed in high-pressure engines, to which Mr. Partington now directed the attention of his auditory, is not more than 30, 40, and seldom exceeds 50 pounds to the inch.

In engines where the pressure is so great, the weight of the atmosphere is not taken into account; and the mode of effecting the motion of the piston is, by allowing one end of the cylinder to be open to the air, whilst the steam acts upon the opposite side of the piston. By this mode of operation, all the parts employed in the ordinary process of condensation are dispensed with, and, consequently, the expense of making those parts, and the friction caused by their operation, is entirely saved. This gives to the engine a peculiar degree of simplicity, but it is unfortunately attended with some danger.

In the generation of high pressure steam, the form of the boiler is an object of considerable importance, and several very ingenious engineers have suggested contrivances for diminishing the probable chance of danger in this essential part of the engine. Among the plans that offer themselves to our notice, that which was suggested by Mr. Woolf has been most generally resorted to.

Mr. Partington then exhibited a small model of Mr. Woolf's steam boiler, consisting of a series of cast-iron tubes, connected by means of screw bolts with the under side of a large vessel A A, which communicates with the engine.

One of the apertures in the upper, or principal boiler, A A, is intended for the admission of water, to supply the waste arising from evaporation, and the others point out the situation of the man-hole and safety-valves. The lecturer described this boiler as

possessing the advantage of diminishing the danger to be apprehended from explosion, as a series of gun barrel tubes may be made much stronger with the same quantity of metal, than a boiler of larger capacity. The lecturer then referred to a large diagram, which shewed Mr. Woolf's method of setting his boiler, as follows:

The principal boiler is still represented at A A, and the figures 1, 2, 3, &c. refer to the corresponding tubes in the previous diagram. B is the fire-place, C the chimney, and the arrows point out the long and waving course of the smoke and flame in their passage to the chimney.*

* In the Philosophical Transactions, No. 461, there is an account of a new way of producing steam of more than ordinary pressure. The boiler consists of an inverted conical vessel of iron, to the base or upper part of which a close and strong copper head or hemisphere is joined by rivets all round: the lower part, or cone, is set in a reverberatory furnace, to receive a sufficient heat from the flame to make it red hot. The water is introduced into this boiler in a number of small streams, or jets, which are injected into it by a pipe, which descends through the cover, or spherical top, of the boiler; and in the middle of the cone several spouts are fixed, radiating from it like the arms of a wheel: the pipe must be carried above the boiler, so as to have a column of a sufficient height to overcome the pressure of the steam, and also enter into the boiler with a considerable force; and by the radiating spouts it is dispersed in a shower upon the interior surface of the iron cone, and is thus converted into steam, which flies up to the copper head, and is carried off by a pipe to the engine. The inventor proposed to make the tube with the radiating spouts to revolve, for the purpose of distributing the water more completely.

Mr. Perkins's engine was here briefly adverted to, and the lecturer produced a working piston from that ingenious engineer's manufactory for the examination of his auditory. It consisted of a number of almost entire circles of metals, forming a series of break-joints; and the inventor stated, that it had been in use for a considerable time, and worked better now than it did at first. This effect must necessarily take place, if the metal be elastic, as it will become more perfectly ground to the form of the cylinder in which it moves. The piston now exhibited did not exceed two and a half inches in diameter, yet it belonged to an engine of ten horse power. The length of its stroke was 14 inches, and it made 158 strokes per minute. This motion appeared to the lecturer much too rapid; he considered that an advantage would be obtained by employing a larger piston, by which less friction is occasioned in proportion to its size. If, for instance, we employ a piston one inch in diameter, with a stroke of ten inches, it is evident that there is much more friction, in proportion to the area of the cylinder, than if we take a piston, the area of which contains ten inches, with a stroke of one inch. The size of the piston should always be proportioned to the stroke required, and the velocity of its motion in the cylinder diminished as much as possible.*

* Mr. Watt very early found, that although most kinds of grease would answer when employed to keep the piston tight, yet that beef or mutton tallow were the most proper,

Among the advantages enumerated by Mr. Perkins as belonging to his steam engine, he states that its weight is not more than two-thirds of that of other engines, and that it consumes only one third of the quantity of fuel which they require. It also sustains, *with perfect safety*, a pressure of 57 atmospheres, or nearly 850 pounds upon every square inch. In fact, it may be stated, that Mr. Perkins's great merit consists in his having shewn that high pressure steam may be employed with perfect safety; to ensure which, it is only necessary to use a boiler which has been proved, by exposing it to a pressure much greater than it is required to sustain, and to pay proper attention to the safety-valve.

There is another circumstance connected with Mr. Perkins's engine, which may be experimentally illustrated. In his machine, steam is generated under great pressure, and the generator or boiler is kept always full by means of a forcing-pump. In speaking of the perfect safety of Mr. Perkins's appa-

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and the least liable to decompose; but when cylinders were new and imperfectly bored, the grease soon disappeared, and the piston was left dry; he therefore endeavoured to detain it by thickening it with some substance which would lubricate the cylinder, and not prove decomposable by heat and exhaustion. Black-lead dust seemed a proper substance, and was therefore employed, especially when a cylinder or the packing of a piston was new; but it was found in the sequel that the black-lead wore the cylinder, though slowly; and by more perfect workmanship, cylinders are made so true as not to require it, or at least only for a very short time at first using.

ratus, the lecturer did not mean to say that his generators never burst, for this circumstance had occurred several times; but when this happened, the only consequence that resulted was the extinction of the fire. If a red hot poker, or a large mass of red hot iron, be plunged into water, a stratum of steam will be seen surrounding it. We know that the bottom of a boiler is hotter than the water it contains, and that a stratum of steam is formed between the boiler and the water, through which the heat must be conveyed. But if we drive an additional quantity of water into the boiler by means of a forcing pump, the contact between the lower surface of the water and the bottom of the vessel is nearly insured. Even in this case, the contact will not be perfect, but the two surfaces will be brought much nearer than if the pump were not resorted to. The lecturer had himself performed an experiment, affording a further illustration of this fact, by immersing a bar of iron in two different vessels of water in succession, and ascertaining by a thermometer the degrees of heat communicated. When the bar was plunged into the first vessel, it was *white hot*, but when removed to the second, it was merely at a *red heat*; yet, strange as it may at first view appear, the temperature of the water was more highly raised in the second than in the first vessel. The reason is, that the elastic vapour which surrounded the iron in the former case, retarded the communication of its heat to the water; while, in the second instance, the

stratum of steam being considerably diminished, the heat of the iron was more readily imparted to the water than when it was in a state of perfect whiteness.

The lecturer here exhibited a model of an engine, in which high pressure steam was employed in conjunction with a condenser. It had a double cylinder, which was first constructed by Hornblower, and afterwards greatly improved by Mr. Woolf. In the common high pressure engine, the steam, after fulfilling its office of elevating or depressing the piston by its expansive force, is discharged into the atmosphere; but in Woolf's engine, instead of being lost, the steam is conveyed from the first cylinder into another of larger dimensions. To effect this object, a double series of pipes is employed, by means of which the upper and lower parts of each cylinder are placed in communication, and the lower part of the first, or smaller cylinder, is connected by a pipe with the upper part of the second, or larger end. If we suppose the two cylinders to be filled with steam, and that the steam in the second cylinder is allowed to escape into the condenser, a vacuum is formed beneath the larger piston, and the high pressure steam below the smaller piston rushing into the space above the larger one, drives it down by its expansive force, while a new portion of steam is admitted above the smaller piston, and causes its depression at the same time. When the two pistons have reached the bottom of the cylinders, the com-

munication between the latter is closed, and the pipes connecting the upper with the lower parts of the cylinder being opened, the same elastic force which has driven down the pistons is introduced beneath them, and they are again driven up. The steam is again conveyed from the larger cylinder to the condenser, and a fresh supply of steam depressing the piston, the operation is repeated. The effective force of the machine is thus considerably augmented, and it becomes a complete *double engine*. It should, however, be stated, in justice to Mr. Watt, that his engine, in its most perfect state, approximates very nearly to that of Mr. Woolf, as the working stroke is completed by the gradual expansion of the steam.

Upon comparing the power of the two engines, it has been found that the same quantity of coals which, with one of Watt's most perfect engines, will raise 30,000,000 of pounds one foot high, will raise nearly 50,000,000 of pounds to the same height with Woolf's engine. The first expense of the latter is, however, proportionably greater, being nearly double that of the former.*

* Messrs. Watt and Boulton suppose a horse capable of raising 32,000 lbs. avoirdupoise one foot high in a minute; while Dr. Desaguliet makes it 27,500 lbs., and Mr. Smeaton only 22,916 : if we divide, therefore, the number of pounds which any steam engine can raise one foot high in a minute by these three numbers, each quotient will represent the number of horses to which the engine is equivalent, according to the estimate of these different engineers. We will take, for example, an engine having a double-acting cylinder, on Mr. Watt's plan, 24 inches diameter, and which

While speaking of the use of high pressure steam, the lecturer said he could not pass unnoticed the steam gun contrived by Mr. Perkins. This destructive missile was then exhibited, and may be better illustrated by reference to a diagram.

A, the chamber of the gun, from which the barrel is charged. B, the handle which directs the piece

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makes 20 strokes per minute, each stroke being five feet long, and the force of steam being equal to a pressure of 10 lbs. per square inch. Required the number of horse-power of such an engine.

The square of the diameter of the cylinder being multiplied by the decimal number .7854, will give the area of the piston: thus, $24 \times 24 = 576 \times .7854 = 452.4$ square inches, which are exposed to the pressure of the steam. Now if we multiply this area by 10 lbs., the pressure upon every square inch, we shall have $452.4 \times 10 = 4524$ lbs., the whole pressure upon the piston, or the weight which the engine is capable of raising with a certain velocity. To find this velocity, we say that the engine performs 20 double strokes, each of five feet long in a minute; the piston must, therefore, move through $20 \times 5 \times 2 = 200$ feet in the same time; and, therefore, the power of the engine will be represented by 4524 lbs. avoirdupoise, raised through 200 feet in a minute, or by $9\frac{1}{4}$ hogsheads of water, ale measure, raised through the same height in the same time. Now this is equivalent to $4524 \times 200 = 904{,}800$ lbs., or $9\frac{1}{4} \times 200 = 1848$ hogsheads raised through the height of one foot in a minute. This is reduced to the horse-power of Messrs. Boulton and Watt, by dividing by 32,000, their estimate of the horse-power: thus, $904{,}800 \div 32{,}000 = 28\frac{1}{4}$ horses.

According to Smeaton, $904{,}800 \div 22{,}916 = 39\frac{1}{2}$ horses.

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* The gun, in fact, is simply formed by introducing a barrel into the steam generator of any engine, and by the addition of two pipes towards the chamber of the gun, which by the action of a handle to the chamber are dropped into the barrel, and fired one by one, at the rate of several hundred in a minute. When a force of 840 lbs. to the square inch is applied, a musket ball, fired at an iron plate 100 feet distance from the gun, is actually driven to pieces in such a way, that none of its fragments can be collected. These guns are said to be more safe than the common guns. Ten cannons upon this principle, it is stated, would in a field of battle be more than equal to 200 on the present system; and a vessel of only 6 guns would be rendered more than a match for a 74: of 500 balls fired every minute from one of these guns, if only one out of 20 were to reach the mark, ten of such guns would destroy 150,000 men daily. By many the perfection of the invention is hailed as a benefaction, which will put a stop to wars and to tyranny;

By employing an engine on the high pressure principle, we are enabled to propel those carriages which are generally termed loco-motive machines. A model of one of those carriages was here exhibited, and the lecturer remarked, that Mr. Blenkinsop, who originally employed high pressure steam for this purpose, found, when he employed a light engine, that there was not sufficient re-action in the rail-road to propel the carriage forward, but that the wheels revolved without moving the machine. To remedy this, he made use of toothed wheels working into similar teeth in the railway, and this plan has since been successfully adopted. A loco-motive engine of this description has frequently drawn twenty loaded waggons along a rail-road at the rate of six, eight, or ten miles an hour. The general application of loco-motive engines, moving on rail-roads for the conveyance of goods and passengers, has indeed been contemplated, and the projectors seem to anticipate the possibility of travelling in this way at the rate of twenty miles an hour; but this was a consummation, the attainment of which the lecturer considered very improbable. It should be remarked, that high pressure steam must necessarily be employed in all loco-motive engines, as it is impossible to carry a sufficient supply of condensing

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water, for they can only convey enough to repair the loss occasioned by the escape of steam into the atmosphere.

The experiment of moving carriages was first successfully employed about the beginning of the present century; and in 1804, a loco-motive engine was in use at a mine at Merthyr Tydvil, in South Wales, and drew as many carriages as contained about ten tons and a half of iron, travelling at the rate of five miles and a half an hour, for a distance of nine miles, without any additional water being required during the time of its journey; its cylinder was eight inches diameter, and the piston had a four feet stroke. The same steam engine, when employed to raise water, worked a pump of eighteen inches and a half diameter, and four feet and a half stroke, raising it twenty-eight feet high, and made eighteen strokes in a minute; it used eighty pounds weight of coals an hour, and in the same time it raised 15,875,160 pounds of water one foot high, the pressure being sixty-five pounds on each square inch of the piston.

While speaking of the loco-motive engine, the lecturer stated that he felt it his duty briefly to advert to Mr. Brown's gas apparatus, which had been proposed by its inventor as a substitute for the steam engine in the propulsion of carriages. Mr. Partington then explained the principle of Mr. Brown's apparatus, and gave it as his opinion, that whatever advantages the apparatus possessed, were more than

counterbalanced by its disadvantages.* In this engine, the motive power is derived from the combus-

* The advantages to be derived from this engine, as detailed in the descriptive outline of the inventor, are,

First, "The quantity of gas consumed being very small, the expense of working the engine is moderate. In its application on land the saving will be extremely great, the cost of the coal gas (deducting the value of the coke) being inconsiderable. The expense of working a marine engine will certainly be greater, as the gas used for that purpose must be extracted from oil, pitch, tar, or some other substance equally portable; yet even in this case, it will not equal the cost of the fuel required to propel a steam-boat; and as a few butts of oil will be sufficient for a long voyage, vessels of the largest tonnage may be propelled to the most distant parts of the world.

Secondly, "The engine is light and portable in its construction, the average weight being less than one-fifth the weight of a steam engine (and boiler) of the same power. It also occupies a much smaller space, and does not require the erection of so strong a building, nor of a lofty chimney. In vessels, the saving of tonnage will be highly advantageous, both in the smaller comparative weight and size of the engine, and in the very reduced space required for fuel.

Thirdly, "This engine is entirely free from danger. No boiler being used, explosions cannot take place; and as the quantity of gas consumed is so small, and the only pressure that of the atmosphere, it is impossibie that the cylinder can burst, or the accidents incidental to steam-boats occur.

"The power of the engine (being derived from the atmospheric pressure of ten pounds and upwards upon the square inch) may be increased with the dimensions of the cylinders, to any extent, and always ascertained by a mercurial guage.

"It is scarcely necessary to allude to the well-known fact, that, after deducting the friction arising from the use of the air and cold-water pumps, &c., the general available power of the condensing steam engine is from seven to eight pounds per square inch.

tion of *carburetted hydrogen gas* in the cylinders,* which by consuming the oxygen of the atmosphere, and rarefying the nitrogen, produces a partial vacuum, and raises water, which falls upon an overshot

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"The cost of the machine will be small, particularly as constructed for raising water; it is, therefore, peculiarly adapted for draining fens, &c. or supplying reservoirs. The expense of wear and tear will also be considerably less than that of the steam engine, and when occasionally out of order, it may be repaired at a trifling cost, and with but little delay."

* The generation of carburetted hydrogen gas for this purpose, as well as for street illumination, is exceedingly simple. It is necessary merely to place a quantity of coal or any other combustible body in a retort, and subject it to the operation of destructive distillation. The gas is almost immediately liberated, and may be conveyed by means of a pipe to the gas-holder, which serves as a reservoir for general use.

A general idea of the process for generating oil gas may be formed from the following account of it:

A quantity of oil is placed in an air-tight vessel in such a manner, that it may flow into retorts which are kept at a moderate red heat, and in such proportions as may regulate the production of gas to a convenient rate; and a stop-cock being employed, this rate may be easily governed, at the will of the operator.

The oil, in its passage through the retorts, is decomposed, and converted into a combustible gas, having the great advantages of being pure and free from sulphurous contamination, and of supporting a very brilliant flame, with the expenditure of very small quantities of the gas.

As a further precaution to purify the gas from oil, which may be suspended in it in the state of vapour, it is conveyed into a wash-vessel, where, by bubbling through water, it is further cooled and rendered fit for use; and passes by a proper pipe into a gasometer, from which it is suffered to branch off in pipes in the usual manner.

water wheel, and thus produces a rotatory motion. This plan may answer the intended purpose in a model upon a small scale, but in its application to large machinery, it is decidedly inferior to Mr. Watt's engine, in which a vacuum is produced in a moment by the condensation of steam, while in Mr. Brown's engine, the rarefied air is condensed with much difficulty by the introduction of considerable quantities of water, and from the bad conducting power of air. Mr. Partington had also observed what he considered as a fallacy, with respect to the perfectness of the vacuum produced by the combustion of the gas in the cylinders. It is true, that a barometer guage, placed in communication with the vacuum part of the machine, was raised to the height of 28 inches or more; but it was evident to him, that this elevation was partly owing to the momentum possessed by the rising column of mercury, which acquired a considerable degree of velocity during its ascent in the barometric tube.

The *application of steam* to the *propulsion of vessels* is usually considered as a modern invention, but this is not the fact; for in an old tract, published as long ago as the year 1730, there is a description of a vessel propelled by steam, constructed by Jonathan Hulls, who states that the object of the invention is "to propel vessels against wind and tide, or in a calm;" and such are precisely the purposes accomplished by modern steam vessels. Mr. Partington here exhibited a large diagram, represent-

ing the steam boat of Jonathan Hulls, which was propelled by an atmospheric steam-engine, connected with paddle wheels, placed at some distance ahead of the boat. Captain Savery, previous to this period, had recommended the adoption of paddle wheels for propelling vessels, but his suggestion was to communicate motion to them, not by steam, but by the labour of men and horses. This plan is actually put in practice in America, where the paddle wheels of vessels are, in some instances, put in motion by horses walking on the deck.

In Britain, steam vessels were first brought into use in 1812 upon the Clyde. They were built at Port-Glasgow, Greenock, and Dumbarton, where the art of ship-building had for many years been conducted by carpenters eminent in their profession. When launched, they were towed at a very trifling expense up the Clyde to Glasgow, situated in the midst of inexhaustible mines of coal and iron, and where the number of skilful practical engineers and artificers rendered the construction of the engines and machinery easy, and the prices moderate.

The early experiments were, of course, made upon a small scale. The first steam boat actually put to use there was the Comet (40 feet keel, 10½ feet beam, 4 wheels, 4 shovel-shaped paddles on each, with a cistern of fresh water to feed the boiler), built by Mr. Henry Bell. She had an engine of only three horses' power, being intended merely for passengers, who, till then, had no other means of con-

veyance on the river than small row boats, either quite open, or supplied with only an awning, to secure them from the weather. Small as this engine was, it rendered the passage certain in one tide, the vessel being able to make head-way even against the wind, and in rough weather.

The success of the first experiment soon excited competition; and a larger vessel, the Elizabeth (with an engine of eight horses' power), was completed in March, 1813, and for a time proved very profitable to the proprietors. The third boat, the Clyde, which began plying in July of the same year, was still larger in her dimensions. The Soho may, however, be considered as one of the largest and fastest going steam vessels yet built in Europe. It is impelled by two engines of sixty horses' power each, and her deck is more than one hundred and sixty feet in length.*

* It is difficult to say what is the maximum speed of steam vessels. Several of those between London and Margate make the voyage in seven hours and a half, a distance of 84 miles. The Hero made the voyage, wind and tide in her favour, in six hours sixteen minutes. The Eclipse, from Belfast to Greenock, 120 or 130 miles, has been known to come in nine hours; and, on one occasion, having about 3000 square feet of canvas set, besides the engine at work, she came from Ailsa to Greenock at the rate of 19 miles. The Henry Bell, a new steam-trader between Glasgow and Liverpool, has delivered goods at various warehouses in Glasgow several hours before the invoices, or advice of the shipment, had arrived in course of post. The New-York steam-vessels run up to Albany, 160 miles, in 21 hours, and down in 19; never in less than 19. They go from New-haven to New-York, 90 miles, in six hours and a half without sail, being nearly 14 miles per hour.

Mr. Partington, having thus completed his comprehensive illustrations of the construction and uses of that amazing monument of mechanical skill, the STEAM ENGINE, concluded his lecture nearly in the following words :—

The series of experimental illustrations selected for this evening's lecture is now brought to a close, and with it the brief course of Lectures which I have had the honour to address to you. In conclusion, however, let me hope that some few words by way of summary will not be considered either as extraneous to the subject in general, or as an additional trespass upon your attention, when I have no farther instructions to communicate.

In those branches of *mechanical* philosophy which we have investigated together, their adaption to the *useful arts of life* has been my chief and primary objects; and I have never been contented with a mere explanation of the present form or intent of the instruments which have been brought before you, but it has always been my desire to give you some sketches of their invention, improvement, and perfection. By these sketches (imperfect as they may have been), the construction of scientific apparatus and mechanical models becomes better understood, and their powers more justly appreciated, which not only incites to successful imitation of what has been already performed, but often leads to the most advantageous results in the useful arts, and to new triumphs in sciences which benefit man. When we

view the great advantages which the commerce and manufactures of this highly favoured land have derived from the labours of philosophy, we see the aphorism of the moral poet fully illustrated——

> "——Serene Philosophy,
> Effusive source of evidence and truth!
> Without thee what were unenlight'ned man?
> A savage roaming through the woods and wilds,
> Rough clad, devoid of every finer art
> And elegance of life."

Such, gentlemen, continued Mr. Partington emphatically, *was* man—what he *is* now, I leave it to your own judgment to appreciate. I see surrounding the lecture-table an audience, consisting perhaps of more than a thousand persons, eager in the pursuit of knowledge, and to whom my humble but zealous exertions appear, from the interest that has been excited, to have imparted somewhat of instruction, combined with amusement. My object, indeed, has been to unite both; and to lay before you the means of exercising those abilities, which, without the assistance of such instructions, might probably remain inactive. Gentlemen, I most respectfully bid you farewell.

APPENDIX.

A Description and Draught of a new-invented Machine, for carrying Vessels or Ships out of, or into any Harbour, Port, or River, against Wind and Tide, or in a Calm. For which His Majesty has granted Letters Patent, for the sole benefit of the Author, for the space of fourteen Years.

By JONATHAN HULLS.

London: Printed for the Author, 1737.

[This highly curious Tract, which the Editor has been permitted to copy, throws considerable light on the History of Steam Navigation. Its great rarity, however, has hitherto prevented its contents becoming generally known to the scientific world, a single copy having been sold for more than *three guineas*.]

An Abstract of the Patent granted to Jonathan Hulls for his new Machine.

"George the Second, by the Grace of God, of Great Britain, France, and Ireland, King, Defender of the Faith, &c.

"To all to whom these presents shall come, greeting.

"Whereas our Trusty and Well-beloved Jonathan Hulls, hath by his Petition humbly represented unto our most dearly Beloved Consort the Queen, Guardian of the Kingdom, &c. That he hath with much Labour and Study, and at great Expense, invented and formed a Machine, for carrying Ships and Vessels out of, or into any Harbour or River, against Wind and Tide, or in Calm, which the Petitioner apprehends, may be of great Service to Our Royal Navy, and Merchant Ships, and to Boats, and to other Vessels, passing against the Stream in Navigable Rivers; of which Machine, the Petitioner hath made Oath, That he is the sole Inventor, as by Affidavit to his said Petition annexed appears: But in regard, the Petitioner apprehends he cannot at present safely discover the nature of his Invention, he proposes to describe the same more fully, by an Instrument in Writing, under his Hand and Seal, to be enrolled in our High Court of Chancery, within a Time, for that purpose given, as has been frequently done in Cases of the like Nature, and has humbly prayed Our said most dearly

Beloved Consort, to grant unto him, his Executors, Administrators and Assigns, our Letters Patent under the Great Seal, for the sole Use and Benefit of his said Invention, within England, Wales, and Town of Berwick upon Tweed, for the Term of Fourteen Years, according to the Statute, in such cases, made and provided.

"Know ye Therefore, That We of Our special Grace, certain Knowledge, and mere Notion, Have given and granted, and by these presents for Us, Our Heirs and Successors, Do give and grant unto the said Jonathan Hulls, his Executors, &c. Our special Licence, full Power, sole Privilege and Authority, during the Term of Years herein expressed, shall and lawfully may make, use, exercise, and mend his said invention of a Machine for carrying Ships and Vessels out of or into any Harbour or River.

"And to the End, that the said Jonathan Hulls, his, &c. and every of them may have and enjoy the full Benefit, and sole Use and Exercise of the said Invention, according to Our Gracious Intention herein before declared, We do by these Presents, for Us, Our Heirs and Successors, require and strictly command All, and every Person or Persons, Bodies Politick and Corporate, and all other Our Subjects whatsoever, of what Estate, Quality, Degree, Name or Condition soever they be, within that part of Our Kingdom of Great Britain called England, &c. that neither they, nor any of them at any Time, during the continuance of the said Term, hereby granted,

view the great advantages which the commerce and manufactures of this highly favoured land have derived from the labours of philosophy, we see the aphorism of the moral poet fully illustrated——

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for, say they, as a few of these guns would sweep away whole armies from the face of the earth, where could the supplies of men be found, and what tyrant could oppress a people who were possessed of them.

water, for they can only convey enough to repair the loss occasioned by the escape of steam into the atmosphere.

The experiment of moving carriages was first successfully employed about the beginning of the present century; and in 1804, a loco-motive engine was in use at a mine at Merthyr Tydvil, in South Wales, and drew as many carriages as contained about ten tons and a half of iron, travelling at the rate of five miles and a half an hour, for a distance of nine miles, without any additional water being required during the time of its journey; its cylinder was eight inches diameter, and the piston had a four feet stroke. The same steam engine, when employed to raise water, worked a pump of eighteen inches and a half diameter, and four feet and a half stroke, raising it twenty-eight feet high, and made eighteen strokes in a minute; it used eighty pounds weight of coals an hour, and in the same time it raised 15,875,160 pounds of water one foot high, the pressure being sixty-five pounds on each square inch of the piston.

While speaking of the loco-motive engine, the lecturer stated that he felt it his duty briefly to advert to Mr. Brown's gas apparatus, which had been proposed by its inventor as a substitute for the steam engine in the propulsion of carriages. Mr. Partington then explained the principle of Mr. Brown's apparatus, and gave it as his opinion, that whatever advantages the apparatus possessed, were more than

counterbalanced by its disadvantages.* In this engine, the motive power is derived from the combus-

* The advantages to be derived from this engine, as detailed in the descriptive outline of the inventor, are,

First, " The quantity of gas consumed being very small, the expense of working the engine is moderate. In its application on land the saving will be extremely great, the cost of the coal gas (deducting the value of the coke) being inconsiderable. The expense of working a marine engine will certainly be greater, as the gas used for that purpose must be extracted from oil, pitch, tar, or some other substance equally portable; yet even in this case, it will not equal the cost of the fuel required to propel a steam-boat; and as a few butts of oil will be sufficient for a long voyage, vessels of the largest tonnage may be propelled to the most distant parts of the world.

Secondly, " The engine is light and portable in its construction, the average weight being less than one-fifth the weight of a steam engine (and boiler) of the same power. It also occupies a much smaller space, and does not require the erection of so strong a building, nor of a lofty chimney. In vessels, the saving of tonnage will be highly advantageous, both in the smaller comparative weight and size of the engine, and in the very reduced space required for fuel.

Thirdly, " This engine is entirely free from danger. No boiler being used, explosions cannot take place; and as the quantity of gas consumed is so small, and the only pressure that of the atmosphere, it is impossibie that the cylinder can burst, or the accidents incidental to steam-boats occur.

" The power of the engine (being derived from the atmospheric pressure of ten pounds and upwards upon the square inch) may be increased with the dimensions of the cylinders, to any extent, and always ascertained by a mercurial guage.

" It is scarcely necessary to allude to the well-known fact, that, after deducting the friction arising from the use of the air and cold-water pumps, &c., the general available power of the condensing steam engine is from seven to eight pounds per square inch.

tion of *carburetted hydrogen gas* in the cylinders,* which by consuming the oxygen of the atmosphere, and rarefying the nitrogen, produces a partial vacuum, and raises water, which falls upon an overshot

"The cost of the machine will be small, particularly as constructed for raising water; it is, therefore, peculiarly adapted for draining fens, &c. or supplying reservoirs. The expense of wear and tear will also be considerably less than that of the steam engine, and when occasionally out of order, it may be repaired at a trifling cost, and with but little delay."

* The generation of carburetted hydrogen gas for this purpose, as well as for street illumination, is exceedingly simple. It is necessary merely to place a quantity of coal or any other combustible body in a retort, and subject it to the operation of destructive distillation. The gas is almost immediately liberated, and may be conveyed by means of a pipe to the gas-holder, which serves as a reservoir for general use.

A general idea of the process for generating oil gas may be formed from the following account of it:

A quantity of oil is placed in an air-tight vessel in such a manner, that it may flow into retorts which are kept at a moderate red heat, and in such proportions as may regulate the production of gas to a convenient rate; and a stop-cock being employed, this rate may be easily governed, at the will of the operator.

The oil, in its passage through the retorts, is decomposed, and converted into a combustible gas, having the great advantages of being pure and free from sulphurous contamination, and of supporting a very brilliant flame, with the expenditure of very small quantities of the gas.

As a further precaution to purify the gas from oil, which may be suspended in it in the state of vapour, it is conveyed into a wash-vessel, where, by bubbling through water, it is further cooled and rendered fit for use; and passes by a proper pipe into a gasometer, from which it is suffered to branch off in pipes in the usual manner.

water wheel, and thus produces a rotatory motion. This plan may answer the intended purpose in a model upon a small scale, but in its application to large machinery, it is decidedly inferior to Mr. Watt's engine, in which a vacuum is produced in a moment by the condensation of steam, while in Mr. Brown's engine, the rarefied air is condensed with much difficulty by the introduction of considerable quantities of water, and from the bad conducting power of air. Mr. Partington had also observed what he considered as a fallacy, with respect to the perfectness of the vacuum produced by the combustion of the gas in the cylinders. It is true, that a barometer guage, placed in communication with the vacuum part of the machine, was raised to the height of 28 inches or more; but it was evident to him, that this elevation was partly owing to the momentum possessed by the rising column of mercury, which acquired a considerable degree of velocity during its ascent in the barometric tube.

The *application of steam* to the *propulsion of vessels* is usually considered as a modern invention, but this is not the fact; for in an old tract, published as long ago as the year 1730, there is a description of a vessel propelled by steam, constructed by Jonathan Hulls, who states that the object of the invention is "to propel vessels against wind and tide, or in a calm;" and such are precisely the purposes accomplished by modern steam vessels. Mr. Partington here exhibited a large diagram, represent-

ing the steam boat of Jonathan Hulls, which was propelled by an atmospheric steam-engine, connected with paddle wheels, placed at some distance ahead of the boat. Captain Savery, previous to this period, had recommended the adoption of paddle wheels for propelling vessels, but his suggestion was to communicate motion to them, not by steam, but by the labour of men and horses. This plan is actually put in practice in America, where the paddle wheels of vessels are, in some instances, put in motion by horses walking on the deck.

In Britain, steam vessels were first brought into use in 1812 upon the Clyde. They were built at Port-Glasgow, Greenock, and Dumbarton, where the art of ship-building had for many years been conducted by carpenters eminent in their profession. When launched, they were towed at a very trifling expense up the Clyde to Glasgow, situated in the midst of inexhaustible mines of coal and iron, and where the number of skilful practical engineers and artificers rendered the construction of the engines and machinery easy, and the prices moderate.

The early experiments were, of course, made upon a small scale. The first steam boat actually put to use there was the Comet (40 feet keel, 10½ feet beam, 4 wheels, 4 shovel-shaped paddles on each, with a cistern of fresh water to feed the boiler), built by Mr. Henry Bell. She had an engine of only three horses' power, being intended merely for passengers, who, till then, had no other means of con-

veyance on the river than small row boats, either quite open, or supplied with only an awning, to secure them from the weather. Small as this engine was, it rendered the passage certain in one tide, the vessel being able to make head-way even against the wind, and in rough weather.

The success of the first experiment soon excited competition; and a larger vessel, the Elizabeth (with an engine of eight horses' power), was completed in March, 1813, and for a time proved very profitable to the proprietors. The third boat, the Clyde, which began plying in July of the same year, was still larger in her dimensions. The Soho may, however, be considered as one of the largest and fastest going steam vessels yet built in Europe. It is impelled by two engines of sixty horses' power each, and her deck is more than one hundred and sixty feet in length.*

* It is difficult to say what is the maximum speed of steam vessels. Several of those between London and Margate make the voyage in seven hours and a half, a distance of 84 miles. The Hero made the voyage, wind and tide in her favour, in six hours sixteen minutes. The Eclipse, from Belfast to Greenock, 120 or 130 miles, has been known to come in nine hours; and, on one occasion, having about 3000 square feet of canvas set, besides the engine at work, she came from Ailsa to Greenock at the rate of 19 miles. The Henry Bell, a new steam-trader between Glasgow and Liverpool, has delivered goods at various warehouses in Glasgow several hours before the invoices, or advice of the shipment, had arrived in course of post. The New-York steam-vessels run up to Albany, 160 miles, in 21 hours, and down in 19; never in less than 19. They go from New-haven to New-York, 90 miles, in six hours and a half without sail, being nearly 14 miles per hour.

Mr. Partington, having thus completed his comprehensive illustrations of the construction and uses of that amazing monument of mechanical skill, the Steam Engine, concluded his lecture nearly in the following words :—

The series of experimental illustrations selected for this evening's lecture is now brought to a close, and with it the brief course of Lectures which I have had the honour to address to you. In conclusion, however, let me hope that some few words by way of summary will not be considered either as extraneous to the subject in general, or as an additional trespass upon your attention, when I have no farther instructions to communicate.

In those branches of *mechanical* philosophy which we have investigated together, their adaption to the *useful arts of life* has been my chief and primary objects; and I have never been contented with a mere explanation of the present form or intent of the instruments which have been brought before you, but it has always been my desire to give you some sketches of their invention, improvement, and perfection. By these sketches (imperfect as they may have been), the construction of scientific apparatus and mechanical models becomes better understood, and their powers more justly appreciated, which not only incites to successful imitation of what has been already performed, but often leads to the most advantageous results in the useful arts, and to new triumphs in sciences which benefit man. When we

view the great advantages which the commerce and manufactures of this highly favoured land have derived from the labours of philosophy, we see the aphorism of the moral poet fully illustrated——

> " ———Serene Philosophy,
> Effusive source of evidence and truth!
> Without thee what were unenlight'ned man?
> A savage roaming through the woods and wilds,
> Rough clad, devoid of every finer art
> And elegance of life."

Such, gentlemen, continued Mr. Partington emphatically, *was* man—what he *is* now, I leave it to your own judgment to appreciate. I see surrounding the lecture-table an audience, consisting perhaps of more than a thousand persons, eager in the pursuit of knowledge, and to whom my humble but zealous exertions appear, from the interest that has been excited, to have imparted somewhat of instruction, combined with amusement. My object, indeed, has been to unite both; and to lay before you the means of exercising those abilities, which, without the assistance of such instructions, might probably remain inactive. Gentlemen, I most respectfully bid you farewell.

APPENDIX.

A Description and Draught of a new-invented Machine, for carrying Vessels or Ships out of, or into any Harbour, Port, or River, against Wind and Tide, or in a Calm. For which His Majesty has granted Letters Patent, for the sole benefit of the Author, for the space of fourteen Years.

By JONATHAN HULLS.

London: Printed for the Author, 1737.

[This highly curious Tract, which the Editor has been permitted to copy, throws considerable light on the History of Steam Navigation. Its great rarity, however, has hitherto prevented its contents becoming generally known to the scientific world, a single copy having been sold for more than *three guineas.*]

An Abstract of the Patent granted to Jonathan Hulls for his new Machine.

"George the Second, by the Grace of God, of Great Britain, France, and Ireland, King, Defender of the Faith, &c.

"To all to whom these presents shall come, greeting.

"Whereas our Trusty and Well-beloved Jonathan Hulls, hath by his Petition humbly represented unto our most dearly Beloved Consort the Queen, Guardian of the Kingdom, &c. That he hath with much Labour and Study, and at great Expense, invented and formed a Machine, for carrying Ships and Vessels out of, or into any Harbour or River, against Wind and Tide, or in Calm, which the Petitioner apprehends, may be of great Service to Our Royal Navy, and Merchant Ships, and to Boats, and to other Vessels, passing against the Stream in Navigable Rivers; of which Machine, the Petitioner hath made Oath, That he is the sole Inventor, as by Affidavit to his said Petition annexed appears: But in regard, the Petitioner apprehends he cannot at present safely discover the nature of his Invention, he proposes to describe the same more fully, by an Instrument in Writing, under his Hand and Seal, to be enrolled in our High Court of Chancery, within a Time, for that purpose given, as has been frequently done in Cases of the like Nature, and has humbly prayed Our said most dearly

Beloved Consort, to grant unto him, his Executors, Administrators and Assigns, our Letters Patent under the Great Seal, for the sole Use and Benefit of his said Invention, within England, Wales, and Town of Berwick upon Tweed, for the Term of Fourteen Years, according to the Statute, in such cases, made and provided.

"Know ye Therefore, That We of Our special Grace, certain Knowledge, and mere Notion, Have given and granted, and by these presents for Us, Our Heirs and Successors, Do give and grant unto the said Jonathan Hulls, his Executors, &c. Our special Licence, full Power, sole Privilege and Authority, during the Term of Years herein expressed, shall and lawfully may make, use, exercise, and mend his said invention of a Machine for carrying Ships and Vessels out of or into any Harbour or River.

"And to the End, that the said Jonathan Hulls, his, &c. and every of them may have and enjoy the full Benefit, and sole Use and Exercise of the said Invention, according to Our Gracious Intention herein before declared, We do by these Presents, for Us, Our Heirs and Successors, require and strictly command All, and every Person or Persons, Bodies Politick and Corporate, and all other Our Subjects whatsoever, of what Estate, Quality, Degree, Name or Condition soever they be, within that part of Our Kingdom of Great Britain called England, &c. that neither they, nor any of them at any Time, during the continuance of the said Term, hereby granted,

either directly or indirectly, do make use or put in practice the said Invention, or any part of the same so attained unto, by Jonathan Hulls as aforesaid, nor in any wise Counterfeit, Imitate, or Resemble the same, nor shall make or cause to be made any Addition thereunto, or Substraction for the same, whereby to pretend himself or themselves the Inventor or Inventors, Devisor or Devisors thereof, without the License, Consent or Agreement of the said Jonathan Hulls, his &c. in writing under his or their Hands and Seals, first had and obtained in that Behalf, upon such Pains and Penalties as can or may be justly inflicted on such Offenders for their contempt of this our Royal Command, and further to be answerable to the said Jonathan Hulls, his Executors, Administrators and Assigns according to Law, for his and their Damages thereby occasioned.

" In witness whereof, We have caused these Our Letters to be made Patent. Witness, Caroline, Queen of Great Britain, &c. Guardian of the said Realm, &c. At Westminster, the 21st Day of December, 1736, in the Tenth Year of our Reign."

By Writ of Privy Seal.

COCKS.

Description, &c.

"Whereas several persons concerned in the navigation have desired some account of my invention for carrying ships out of and into harbours, ports, and rivers, when they have not a fair wind.

"But I could not fully describe this machine without writing a small Treatise of the same, in which I shall endeavour to demonstrate the possibility and probability of the matter undertaken.

"There is one great hardship lies too commonly upon those who propose to advance some new, though useful, scheme for the public benefit. The world, abounding more in rash censure than in a candid and unprejudiced estimation of things, if a person does not answer their expectation in every point, instead of friendly treatment for his good intentions, he too often meets with ridicule and contempt.

"But I hope that this will not be my case; but that they will form a judgment of my present undertaking only from trial. If it should be said that I have filled this tract with things that are foreign to the matter proposed, I answer, there is nothing in it but what is necessary to be understood by those that desire to know the nature of that machine, which I now offer to the world; and I hope, that through the blessing of God it may prove serviceable to my country.

"J. H."

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"J. H."

A Description and Draught, &c.

"Before I speak of the machine itself, it will be necessary to explain the nature of those powers that are applied to it. And first of

Mechanical Powers.

"The intent of most mechanical machines is to raise great power or weight with a small intensity of force; or, on the other hand, to cause a motion to be more swift, or to continue a motion a long space of time by a greater weight or force. But there was never any instrument yet could be made to move a heavy body by a lighter, through equal perpendicular space. If that could be performed, the perpetual motion might be easily brought to perfection; but where nature contradicts, it is in vain to attempt.

"It is possible to make a machine to lift up an immense weight with a small string, or even a hair; but then we must take notice, there must be time and space in proportion to the weight of the body to be so raised; for one general rule to be observed in mechanical powers is, when the spaces gone through are in an inverse ratio of the intensities, the actions are equal.

Demonstration.

"We will instance in the balance-beam, a well known instrument.

"The action of a weight to move a balance is by

so much greater, as the point pressed by the weight is more distant from the centre of the balance, and that action follows the proportion of the distance of the said point from the centre. When the balance moves about its centre C, the point B describes the arch B b, whilst the point A describes the arch A a, which is the biggest of the two; therefore, in that motion of the balance, the action of the same weight is different, according to the point to which it is applied, and it follows the proportion of the space gone through by that point, therefore at A it is as A a, and at B it is as B b, but those arches are to one another as C A to C B.

"The brachia, or arms of the balance are divided into equal parts, and one ounce applied to the ninth division from the centre is as powerful as three ounces at the third division, and two ounces at the sixth division act as strongly as three at the fourth, &c. A balance is said to be in equilibrio when the actions of the weights upon each brachium to move the balance are equal, so that they mutually destroy each other by the foregoing experiment. Unequal weights can æquiponderate: for this, it is requisite that the distance from the centre be reciprocally as the weights; in that case, if each weight be multiplied by its distance, the products will be equal. On this principle are steelyards made to weigh with one weight.

Of the axis in Peritrochio.

"The power hath the greater force the greater the wheel is; and its action increases in the same ratio with the wheel's diameter; the weight resists so much the less as the diameter of the axis is less; and its resistance is diminished in the same ratio as the diameter of the axis; and that there may be an equilibrium between the weight and the power, it is always requisite that the diameter of the wheel be to the diameter of the axis in an inverse ratio of the power to the weight.

For example, suppose the diameter of the axis to be one foot, and the diameter of the wheel six feet; if the weight D weigh six hundred pounds, and the weight at B one hundred pounds, there will be an equilibrium; and if it is required to raise the weight D, the weight at B must descend six feet, in order to raise the weight at D one foot.

There are many sorts of machines to raise great weights, as the pulley, &c., but they are all grounded on the same principles with these already mentioned; for if a great weight is to be raised by a small power, this small power must go through the larger space in proportion to the inequality of the power with the weight.*

* There ought to be some allowance added to the power that moves any machine, more than the rules of mechanics mention, by reason of friction, which is more or less, according to the nature of the machine; for the larger a wheel, &c. is, and the lesser the axis, the less will the friction be, and contra.—*Note by J. Hulls.*

But since our present purpose cannot be completed by any mechanical rules only (because there can no motion be contrived to be worked by manual operation, to move both with power and with swiftness sufficient to answer the intended work); in order, therefore, to drive this machine, we are forced to apply the weight of the atmosphere, the nature of which I shall now endeavour to explain.

The atmosphere being an invisible fluid, it will be proper to give some account of fluids in general.

Of Fluids.

A fluid is a body whose parts yield to any force impressed, and by yielding are very easily removed one among another. Hence it follows, that fluidity arises from this, that the parts do not strongly cohere, and that the motion is not hindered by any inequality in the surface of the parts.

Fluids agree in this with solid bodies, *viz.* that they consist of heavy particles, and have their gravity proportionable to the quantity of matter, in any position of their parts. From this gravity it follows, that the surface of a fluid contained in a vessel, if it be not pressed from above, or if equally pressed (for that makes no alteration), will become plain or flat, and parallel to the horizon; for as the particles yield to any force impressed, they will be moved by gravity, till at last none of them can descend any lower. The lower parts sustain the upper, and are

pressed by them, and this pressure is in proportion to the incumbent matter; that is, to the height of the liquid above the particle that is pressed. But as the upper surface of the liquid is parallel to the horizon, all the points of any surface which you may conceive, within the liquid parallel to the horizon, are equally pressed.

If, therefore, in any part of such a surface there is a pressure less than in other parts, the liquid which yields to any impression, will ascend till the pressure becomes equal.

Example.—Take a glass tube, open at both ends, and stopping one end with your finger, immerse the other in water; when the tube is full of air, the water will rise but to a small height: if you take away your finger that the air that is compressed may go out, the imaginary surface that you conceive in the water just at the bottom of the tube is less pressed, just against the hole of the tube, so that the water will rise up in the tube till it comes up to the same height with the external water.

The pressure upon the lower parts, which arises from the gravity of the super-incumbent liquid, exerts itself in every direction, and every way equally.

In tubes that have a communication, whether equal or unequal, whether straight or oblique, a fluid rises to the same height, that is, all the parts of the upper surface are in the same horizontal plane.

The modern philosophers conceive fluids to consist of particles, small, smooth, hard, and spherical,

according to which opinion, every particle is of itself solid, or a fixed body, and, when considered singly, is no fluid, but becomes so only by being joined with particles of the same kind.

The more perfect a fluid is, the more easily it will yield to all impressions, and the more easily will the parts coalesce being separated. Properly speaking, there is no perfect fluid in nature, by reason of their attraction; for mercury, the most perfect fluid, is not exempt from it.

Of the Action of a Liquid against the bottom and sides of the Vessel that contains it.

As the pressure of liquids are every way equal, the bottom and sides are pressed as much as the neighbouring parts of the liquid, therefore this action increases in proportion to the height of the liquid, and is every way equal at the same depth, depending altogether upon the height, and not at all upon the quantity of the liquid. Therefore, when the height of the liquid and the size of the bottom remain the same, the action upon the bottom is always equal, however the shape of the body be changed. In every case the pressure sustained in the bottom is equal to the weight of a column of water, whose base is from the bottom itself, and the height of the vertical distance of the upper surface of the water from the bottom itself.

To explain this, take a cylinder of a certain base, that will hold perhaps a gallon. This vessel being filled, the bottom will be allowed to sustain the

whole weight of the fluid therein contained, gravity acting in a right line and perpendicularly. Again, take another vessel of equal height and base, partly cylindrical and partly flanched out, the top being in the form of the frustrum of a cone. This vessel, suppose, will hold two gallons: then take a third vessel of equal base and but half the height; to make it, however, of equal height with the other two, let a small pipe be soldered into the lid. Let this vessel contain in the whole but half a gallon. If these be severally filled with a fluid of the same kind, we say that the bottoms and sides of each of these shall be pressed thereby alike.

If the cylindrical part of our second vessel mentioned were continued to the top, the fluid thereby inclosed would be just in the same circumstances as that in the vessel first mentioned; and then the side water contained in the conical part would bear against the cylinder, supposed to be continued to the top, as if the water therein was frozen, on the one hand, and bearing against the sides of the conical part on the other, according to the height of the fluid contained between them. Imagine, then, the continuation of the cylinder removed, or the water frozen therein to thaw, the pressure of the side water would lay against the fluid cylinder itself, which being in all parts of equal weight and moment with itself, will be thereby sustained quiet and motionless in its proper place, and it will be supported on the other side in like manner by the sloping sides of the vessel; nor would the weight on the bottom, or against the

fixed cylindric sides of this vessel, be at all increased by the alteration proposed.

It must, however, be admitted, that as there is double the quantity of matter by supposition contained in a vessel of this form that was in the vessel first mentioned, the absolute weight together will be proportionable thereto. But then, again, it must be considered, that this increase of weight and pressure affect only the shelving sides of the second vessel: and as these, by their disposition, become an inclined plane, they are doubtless made to bear the difference of weight proposed, which must be thereby communicated to, and supported by the upright sides of the cylindric part whereon they rest; but on the area of the internal base, and against the sides of the cylinder within, no more weight is laid than barely that of the height of the fluid above them.

To prove that the water in the small tube, in the vessel last mentioned, presses against the bottom and sides, and top of the vessel, according to its height, we have the following experiment:

Take two round boards of about a foot diameter, and join them together with leather in the manner of bellows, that they may hold water, and in the topmost board screw in a small tube of a considerable length, as four feet: place a weight on the top of this vessel nearly equal in weight to a pillar of water of twelve inches diameter and four feet high: keep pouring water into this tube at the top, and it will raise the weight, notwithstanding the water in the

tube is not near so heavy as the weight on this board, as Fig. 7. Or, if you were to fill this vessel with water, and lay on more weight than the weight of the largest column up to the top, this weight would drive the water out at the top of the small tube: for as in mechanical instruments a heavy body will force a lighter, a larger space and a light body, by passing a larger space, will raise a heavy body a small space; therefore weights are to their spaces in an inverse ratio, as hath been already demonstrated.

Hence it follows, that every drop which is at rest endeavours to recede every way with equal force. If, therefore, it be pressed on one side, it endeavours to recede that way with the same force, because action and re-action are equal, and with that very force it will press every way.

This is proved by several experiments. I shall instance in one more.

Fix up a balance beam, and to one end hang a vessel of water partly full, made in a cylindrical form, and at the other end hang weights: then take some solid body into your hand, and immerse the same into the liquid, not touching the bottom nor sides: then hang on weights to make an equilibrium, the solid being immersed to a certain depth, those weights will be the weight of the whole water, were it filled up to the place the water rose to when this solid was immersed.

Of Solids immersed in Liquids.

The different gravity of bodies, whether solids or liquids, arises from this, that they contain a greater or less quantity of matter in an unequal space.

Definition I.

The quantity of matter in a body being considered in relation to the space possessed by it, is called the density or specific gravity of the body. A body is said to have double or triple, &c. the density of another body, when, supposing their bulks equal, it contains a double or triple, &c. quantity of matter.

Definition II.

A body is said to be homogeneous, when it is everywhere of the same density.

Definition III.

Heterogeneous, when the density is unequal in different parts of the body.

Definition IV.

The gravity of a body, considered with relation to its bulk, is called the specific gravity of a body.

The specific gravity is said to be double, when under the same bulk the weight is double. Therefore the specific gravities and densities of homogeneous bodies are in the same ratio, and they are to one another as the weights of equal bodies in respect

to their bulk. If homogeneous bodies are of the same weight, their bulks will be so much less as their densities are greater; and under the same weight the bulk is diminished, in the same ratio in which the density is increased; therefore, in that case, the bulks are inversely as the densities.

On the Specific Gravity of Bodies.

Aristotle's notion of the elements was, that the earth and water were positively heavy, fire positively light, and air indifferent as to either. His followers, therefore, affirm, that the ascent of bodies is owing to their positive levity, that of flame and smoke for instance. But in this they are mistaken, for bodies are only relatively light or heavy accordingly as they are compared with others of a different kind; so that flame or smoke ascend, not because they are really light, but because they are buoyèd up by the air, which is more dense, and in its nature heavier than they, for flame in vacuo will soon subside, and smoke, when the fuliginous or sooty parts thereof become heavier than the medium round them, will visibly descend. Thus oil and wine do not swim on water because of their own levity, but because water is a heavier fluid, and sinks in them. In air most bodies sink, because it is very light; in water not so many, it being far more dense; in mercury scarce any may be totally immersed from the like cause: nor is there any greater reason that cork should be termed light because it will swim in water, than that

iron should be esteemed so because it will swim in mercury.

In general, therefore, one body is said to be specifically heavier or denser than another when it contains more matter, or a greater degree of weight under the same or an equal bulk, or an equal degree of weight in less space or compass. For instance, a cubic inch of gold weighs ten ounces troy; an equal quantity of lead hardly six; of common water something better than half an ounce; so that gold is about nineteen, and lead about eleven, times denser or specifically heavier than water, and thus of any other.*

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* The specific gravities of metals will be best understood by reference to the following list. *Editor.*

1.	Platinum	21,00
2.	Gold	19,30
3.	Tungsten	17,50
4.	Mercury	13,50
5.	Palladium	11,50
6.	Lead	11,35
7.	Silver	10,50
8.	Bismuth	9,80
9.	Uranium	9,00
10.	Copper	8,90
11.	Arsenic	8,35
12.	Nickel	8,25
13.	Cobalt	8,00
14.	Iron	7,78
15.	Molybdenum	7,40
16.	Tin	7,30
17.	Zinc	7,00
18.	Manganese	6,85
19.	Antimony	6,70

Specific gravity, then, is that which is peculiar to any body, whereby it may be distinguished from bodies of a different kind. It is sometimes, and not improperly, called relative or comparative gravity, to distinguish it from absolute or positive gravity, which last increases always in proportion to the bulk of the body, weighed directly, the other not; absolutely considered, a pound of one thing is as heavy as a pound of another, without regard to what their specific gravity is, but their relative gravity or bulk is very different.

A body specifically heavier than a fluid will sink therein, because it weighs more than the fluid displaced by it, and whose room it takes up; so that the imaginary surface immediately under the body being there more pressed than by the water in any other part, it therefore yields and lets it through. But a body specifically lighter than a fluid will always rise therein, because it presses less on the imaginary surface beneath it, than the fluid would in whose place it is substituted. Were there any necessity of proving this by experiment, it might be done thus: take a small glass bolt-head (which were it solid and of a lump would be near three times heavier than water, but being hollow, and full of air only, it will swim), this may be so nicely filled with water by the stem that at the top of a jar it may

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20. Tellurium	6,10
21. Sodium	0,972
22. Potassium....................	0,865

swim, in the middle it may remain at a poise, and put beyond that it will sink.

This will be brought about by the spring of the air included therein, which being compressible, will either contract or dilate itself, according to the degree of pressure it is under. Toward the upper part of the jar it will be pressed by little more than the atmosphere; toward the middle, by the atmosphere, and some inches perhaps of water; and at the bottom, by more water still. In the first case, the air in the machine cannot be so much pressed as in the second; in the second, not so much as in the last; whence the mouth of the machine being unstopped, as the pressure is increased, more water will be gradually thrust into it, making the whole specifically more heavy, and so will produce the afore-mentioned effect, which will be visible, tried on a machine that is small.

Of the Densities of Liquids.

When the pressures of two liquids are equal, the quantities of matter in columns that have equal bases do not differ, wherefore the bulks, that is, the heights of the columns are inversely as the densities, whence may be deduced the method of comparing them together.

Experiment I.

Pour mercury into a curve tube A, so as to fill the lower part of the tube from B to C; pour in

water in one leg from B to E, in the other leg pour oil of turpentine, till both the surfaces of mercury B C be in the same horizontal line, and the height of the oil be C D, these heights will be as 87 to 100, which is in the inverse ratio that the density of the water has to the density of the oil of turpentine, and therefore these densities are to each other as 100 to 87. The mercury is poured in first, lest the liquids should be mixed in the bottom of the tube.

The densities of liquids are also compared together by immersing a solid in them; for if a solid lighter than the liquid is to be compared together, they should be immersed successively into different liquids; the immersed parts will be inversely as the densities of the liquids: for, because the same solid is made use of, the portions of the different liquors, which in every case would fill the space taken up by the immersed part, are of the same weight; therefore the bulks of those portions, that is, the immersed parts themselves, are inversely as the densities.

To prove that the weight of the air forces fluids, as it were, seemingly to hang in a tube to such a height, according to the gravity of the fluid in such tube, mercury will be forced about 29 inches, and water about 31 feet: and if the air is drawn out of the tube, no fluid will rise any higher than to such height, as the weight of the fluid makes an equilibrium with the weight of the atmosphere.

As air is proved to have gravity according to its

density as well as other fluids, it is easy conceived the nature of its pressing the mercury in the barometer to such a height. It is not because nature abhors a vacuum (as some imagine), for if that were the case, there would be no vacuum in the top were the tube of ever so great a length.

The instrument called the barometer is to find the weight of the air at such a present time, and to shew the difference of the weight at different times. The different pressure of the atmosphere may very well be supposed to arise from the alteration of the height, for, as in other fluids, the deeper they are the greater the pressure at the bottom.

To make this matter more plain, take this example: take a barometer that is turned at the bottom (as they now commonly make them), as Fig. 20, and join to the bottom of some pipe that comes from the top of some edifice, and being filled with water, will drive the mercury to the top of the glass tube, by reason of the weight of the pillar of water and atmosphere both press on the mercury; but unstop the top of the tube A, and the air will press equally upon A and B; therefore the pillar of mercury gives the weight of the pillar of water, only of the same size as the tube A; for let the pillar of water be of what size soever, the pillar of mercury balances no more than a pillar of its own size, for the reasons before described. And if you add to, or diminish from the top of the tube B, the mercury will respec-

water in one leg from B to E, in the oth , or
oil of turpentine, till both the surfac
B C be in the same horizontal line. .er 5 or 6
the oil be C D, these heights w' immerse the
which is in the inverse ratio ' , the mercury will
water has to the density o' the cistern, until the
therefore these densiti the tube is about the height
87. The mercury i cording to the weight of the
should be mixed ; time) ; then if you immerse this
The densi' the mercury will rise one inch
gether by i sinking fourteen.
lighter tubes and join them together, so
they s' shall have a communication at the bottom
liqr hole, put some mercury into one of the
d and it will rise to an equal height in both ;
then pour in water into either, until this water has driven out all the mercury into one tube, and then stop, and you will find the water to stand about 14 times as high as the mercury, because they equiponderate at those heights.

It may be observed what an exact equilibrium is made by fluids; for, if you disturb the mercury in the cistern wherein the barometer is immersed, you

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* The mercury is to be measured from the horizontal line from the top of the mercury in the short end of the glass tube; the water in B will stand fourteen times as high as the mercury in A; therefore if you measure the height of the mercury, and have recourse to the table of specific gravity, you may calculate the height of this pillar of water, and the weight of the same. *Note by J. Hulls.*

mercury act in the tube in the same
ce balance-beam that equiponderates.
tube of a considerable length, and
mercury in, stop it at the lower
it in water 14 times as deep as the
e mercury in the tube, and then unstop
wer end, the mercury will not fall out, notwithstanding the tube is open at both ends. If the tube is immersed deeper, the mercury will rise higher in the tube, which demonstrates that fluids are pressed upwards as well as downwards, in proportion to the height of the fluid above, and the gravity of the same.

If a man's body were to bear the weight of the atmosphere in proportion to the superficial content of his body (as has been imagined), the strength of his bones and sinews could not sustain it; but if you cut a hole in the top of a large vessel, and then lay your body on it in such a manner as that the air cannot pass by you into the vessel, and then pump the air out of the vessel, you will very sensibly feel the weight of the air; for if the hole is large, you will not be able to separate yourself from the vessel, but when the air is let in you are immediately relieved.

Since it is demonstrated, that the air is of itself of such weight, it may seem strange it is not more sensibly felt to press on human bodies. The reason is this: there is no particle in a man's body but is made up with matter full as heavy as air, and most of the particles a great deal heavier, therefore every

tively rise or fall one 14th of the length added to, or diminished from the tube B.*

Again, if you were to take a barometer 5 or 6 feet long and fill it with mercury, and immerse the open end into a cistern of the same, the mercury will sink down out of the tube into the cistern, until the height of the mercury in the tube is about the height of 29 or 30 inches (according to the weight of the atmosphere at that time); then if you immerse this instrument in water, the mercury will rise one inch for the instrument's sinking fourteen.

If you take two tubes and join them together, so that they shall have a communication at the bottom by a small hole, put some mercury into one of the tubes, and it will rise to an equal height in both; then pour in water into either, until this water has driven out all the mercury into one tube, and then stop, and you will find the water to stand about 14 times as high as the mercury, because they equiponderate at those heights.

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will see the mercury act in the tube in the same manner as a nice balance-beam that equiponderates.

If you take a tube of a considerable length, and put a quantity of mercury in, stop it at the lower end, and immerse it in water 14 times as deep as the length of the mercury in the tube, and then unstop the lower end, the mercury will not fall out, notwithstanding the tube is open at both ends. If the tube is immersed deeper, the mercury will rise higher in the tube, which demonstrates that fluids are pressed upwards as well as downwards, in proportion to the height of the fluid above, and the gravity of the same.

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Since it is demonstrated, that the air is of itself of such weight, it may seem strange it is not more sensibly felt to press on human bodies. The reason is this: there is no particle in a man's body but is made up with matter full as heavy as air, and most of the particles a great deal heavier, therefore every

part defends itself within and without, without being pressed in; for every body that is heavier than a fluid being immersed therein, defends itself from external pressure. For when you immerse a soft body, that is homogeneous in water, ever so deep, if this body is more dense than water, the pressure of the water will not alter the form of this soft body.

For if a person were to descend to the bottom of a well full of water, his body would be pressed the same as if he descended the same depth into the sea, for there is the same pressure against a pool-head as there is against the sea-bank at the same depth, as hath been before demonstrated.

Thus I have endeavoured to explain the nature of the pressure of the air on other bodies, by comparing it with other fluids that are visible to our eye, as mercury, water, &c.; and since the pressure is so very great, it is the more fit to be applied to a purpose wherein all sorts of manual operations are insufficient. For this present undertaking cannot be supposed to be done by strength of men or horses, or by any machine driven by either.

Lastly, the atmosphere being of a great weight, and striving to get in where there is a vacuum, I shall endeavour to shew how this vacuum is made, and in what manner this force is applied to drive the machine.

In some convenient part of the tow-boat, as shewn in the plate, there is placed a vessel about two-thirds full of water, with the top close shut, this

vessel being kept boiling, rarifies the water into steam; this steam being conveyed through a large pipe into a cylindrical vessel, and there condensed, makes a vacuum, which causes the weight of the atmosphere to press on this vessel, and so presses down a piston that is fitted into this cylindrical vessel, in the same manner as in Mr. Newcomen's engine, with which he raises water by fire. See Fig. 30.

P the pipe coming from the furnace to the cylinder.

First, the cylinder, wherein the steam is condensed.

R the valve that stops the steam from coming into the cylinder, whilst the steam within the same is condensed.

S the pipe to convey the condensing water into the cylinder.

T a cock to let in the condensing water when the cylinder is full of steam, and the valve P is shut.

U a rope fixed to the piston that slides up and down the cylinder. This rope U is the same rope that goes round the wheel D in the machine.

It hath been already demonstrated, that a vessel of 30 inches diameter, which is but two feet and a half, when the air is driven out, the atmosphere will press on it to the weight of 4 ton 16 hundred and upwards: when proper instruments for this work are applied to it, it must drive a vessel with a great force.

The bigness of the machines may be proportioned

to the work that is to be performed by them ; but if such a force as is applied in this first essay be not sufficient for any purpose that may be required, there is room to make such addition as will move an immense weight with tolerable swiftness.

It is my opinion it will not be found practicable to place the machine, here recommended, in the vessel itself that is to be taken in or out of the port, &c. but rather in a separate vessel, for these reasons :

1. This machine may be brought cumbersome, and to take up too much room in a vessel laden with goods, provisions, &c.

2. If this machine is put in a separate vessel, this vessel may lie at any port, &c. to be ready on all occasions.

3. A vessel of a small burthen will be sufficient to carry the machine to take out a large one.

4. A vessel will serve for this purpose for many years, after she is thrown off, and not safe to be taken far abroad.

The Explanation of the Machine.

A, represents the chimney coming from the furnace.

B, the tow-boat.

C C, two pieces of timber framed together to carry the machine.

D *a*, D and D *b*, are three wheels on one axis, to receive the ropes M, F *b*, and F *a*.

H *a* and H *b* are two wheels on the same axis with the fans I I I I I I, which move alternately in

such a manner, that when the wheels D *a*, D, and D *b* move backward or forward, they keep the fans I I I I I I in a direct motion.

F *b* is a rope going from H *b* to D *b*, that when the wheel D *a*, D, and D *b* move forward, moves the wheel H *b* forwards, which brings the fans forward with it.

F *a* is a rope going from the wheel H *a* to the wheel D *a*, that when the wheels D *a*, D, and D *b* move forward, the wheel H *a* draws the rope F, and raises the weight G, at the same time as the wheel H *b* brings the fans forward.

When the weight G is so raised, while the wheels D *a*, D, and D *b* are moving backward, the rope F *a* gives way, and the power of the weight G brings the wheel H *a* forward, and the fans with it, so that the fans always keep going forward, notwithstanding the wheels D *a*, D, and D *b* move backwards and forwards as the piston moves up and down the cylinder.

L L are teeth for a catch to drop in from the axis, and are so contrived that they catch in an alternate manner, to cause the fans to move always forward, for the wheel H *a*, by the power of the weight G, is performing his office, while the other wheel, H *b*, goes back in order to fetch another stroke.

The weight G must contain but half the weight of the pillar of air pressing upon the piston, because the weight G is raised at the same time as the wheel

H *b* performs its office, so that it is in effect two machines acting alternately by the weight of one pillar of air, of such a diameter as the diameter of the cylinder is.

If it should be said, that this is not a new invention, because I make use of the same power to drive my machine that others have made use of to drive theirs for other purposes, I answer, the application of this power is no more than the application of any common and known instrument used in mechanism for new-invented purposes.

Answers to some Queries that have been made concerning the Possibility and Usefulness of this Undertaking.

Query I.

Is it possible to fix instruments of sufficient strength to move so prodigious a weight as may be contained in a very large vesssel ?

Answer.—All mechanics will allow it is possible to make a machine to move an immense weight, if there is force enough to drive the same; for every member must be made in a proportionable strength to the intended work, and properly braced with laces of iron, &c., so that no part can give way or break. If the braces, &c. necessary for this work had been put in the draught, it would have been so much crowded with lines, that the main instruments could not be so well perceived.

Query II.

Will not the force of the waves break any instrument to pieces that is placed to move in the water?

Answer.—First, It cannot be supposed that this machine will be used in a storm or tempest at sea, when the waves are very rough; for if a merchant lies in a harbour, &c. he would not choose to put out to sea in a storm, if it were possible to get out, but rather stay until it is abated.

Secondly, When the wind comes a-head of the tow-boat, the fans will be protected by it from the violence of the waves; and when the wind comes sideways, the waves will come edgeways of the fans, and therefore strike them with the less force.

Thirdly, There may be pieces of timber laid to swim on the surface of the water on each side of the fans, and so contrived as they shall not touch them, which will protect them from the force of the waves.

Up in-land rivers, where the bottom can possibly be reached, the fans may be taken out, and cranks placed at the hindmost axis to strike a shaft to the bottom of the river, which will drive the vessel forward with the greater force.*

* It is a very curious fact, that a patent has lately been obtained for this mode of impelling vessels; and a

Query III.

It being a continual expence to keep this machine at work, will the expense be answered?

Answer.—The work to be done by this machine will be upon particular occasions, when all other means yet found out are wholly insufficient. How often does a merchant wish that his ship were on the ocean, when, if he were there, the wind would serve tolerably well to carry him on his intended voyage, but does not serve at the same time to carry him out of the river, &c. he happens to be in, which a few hours' work of this machine would do. Besides, I know engines that are driven by the same power as this is, where materials for the purpose are dearer than in any navigable river in England; therefore experience demonstrates, that the expense will be but a trifle to the value of the work performed by those sort of machines, which any person that knows the nature of those things may easily calculate.

Thus I have endeavoured to give a clear and satisfactory account of my new-invented machine, for carrying vessels out of and into any port, harbour, or river, against wind and tide, or in a calm; and I doubt not, but whoever shall give himself

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nearly similar species of locomotion has formed the groundwork of another patent for engines on land.—*Editor.*

the trouble to peruse this Essay, will be so candid as to excuse or overlook any imperfections in the diction or manner of writing, considering the hand it comes from: if what I have imagined may only appear as plain to others as it has done to me, *viz.* that the scheme I now offer is *practicable,* and if encouraged will be *useful.**

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* The plain good sense evinced by the projector of steam navigation, and the very palpable truth conveyed in the last sentence of this admirable little Treatise, furnish the clearest evidence of the justice of our claim to the priority of invention, and awards to Great Britain a new link in the history of her naval triumphs.

In concluding this important subject, we must not, however, forget to notice the spirit of prophecy displayed by Dr. Darwin at a subsequent period. It occurs in the "Botanic Garden," and is to the following effect:—

> " Soon shall thy arm, unconquered Steam, afar!
> *Drag the slow barge,* or *drive the rapid car;*
> Or on wide waving wings expanded bear
> The flying chariot through the fields of air."

The propulsion of boats by steam, like that of carriages, has long ceased to be problematic; and it is a curious fact, that Sir George Cayley, having entered into a mathematical investigation of the powers of steam machinery when compared with the muscular force of birds, has come to the conclusion, that such an attempt is not merely feasible, but might be undertaken with every possible chance of success.—*Editor.*

INDEX.

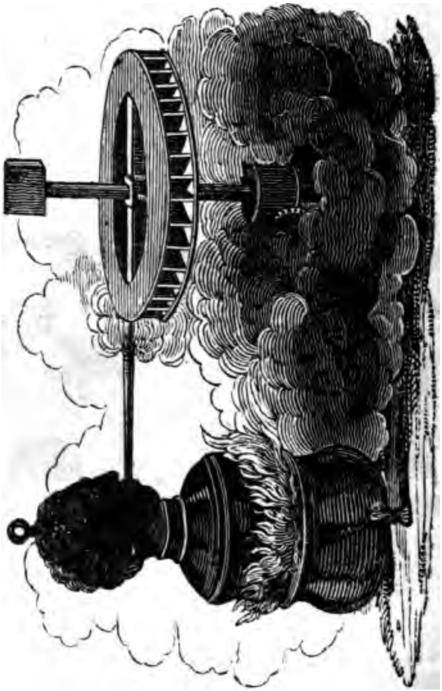
Coe & Moore, Printers, 27, Old Change.

Page 2.

Fig. **1.**

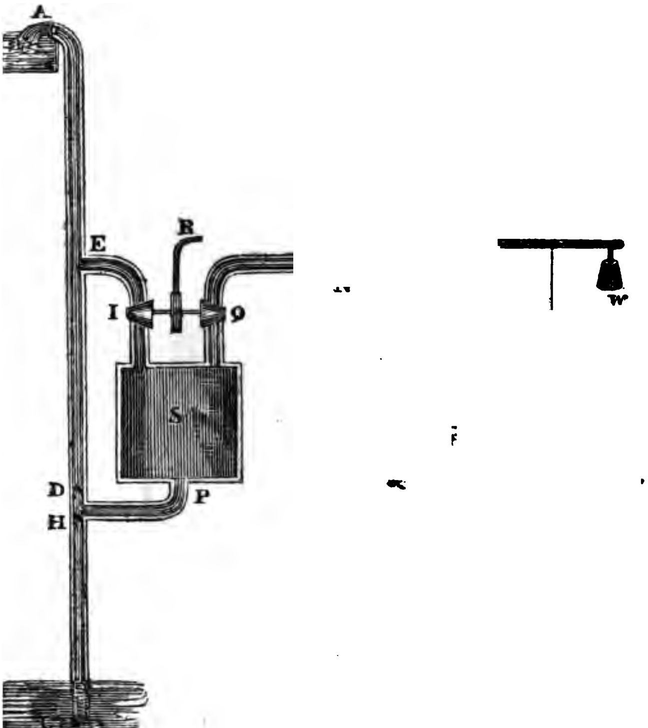
Hero's Engine.

Fig. 2.



BRANCA'S APPARATUS.

Fig. 3.



SAVERY'S ENGINE.

Page 13.

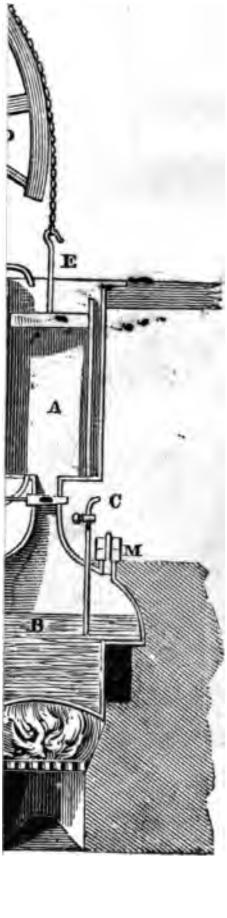


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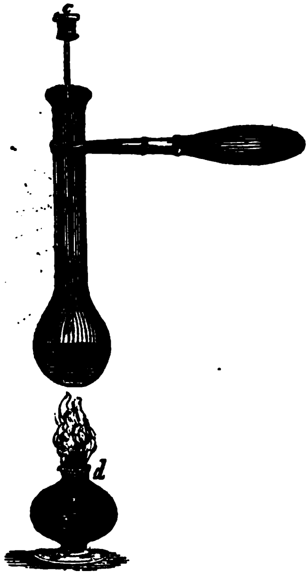
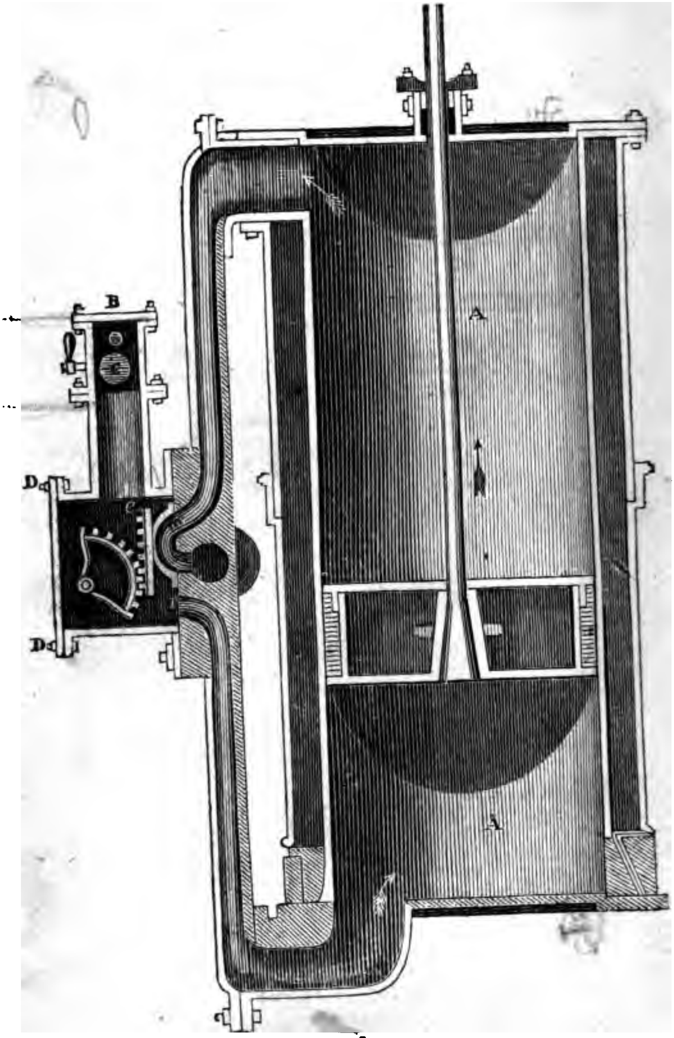
Fig. 5.



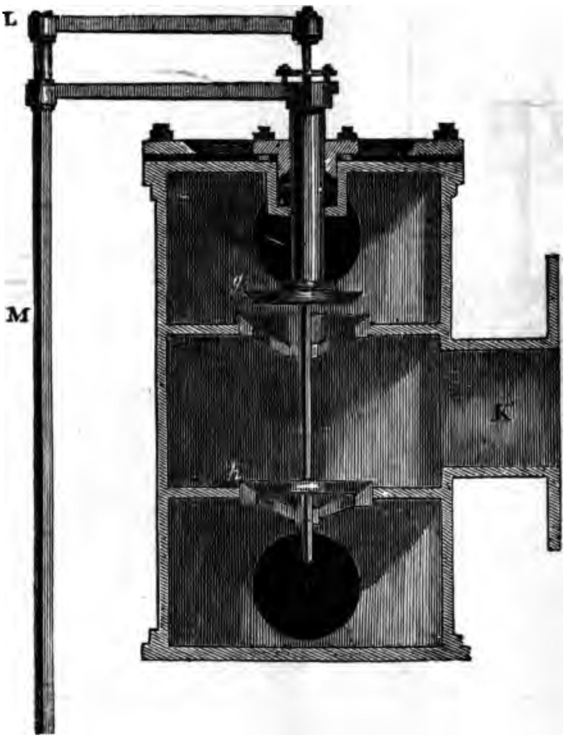
GLASS ATMOSPHERIC APPARATUS.

Fig. 6.



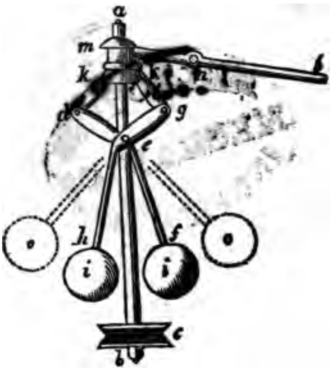
DOUBLE ACTING ENGINE.

Fig. 7.



CONICAL VALVES.

Fig. 8.



GOVERNOR.

Fig. 11.

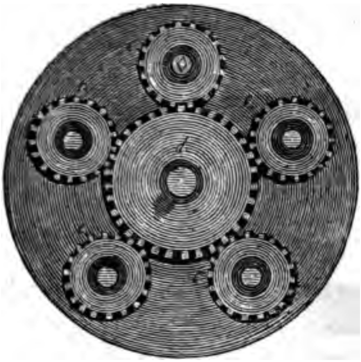


Fig. 10.

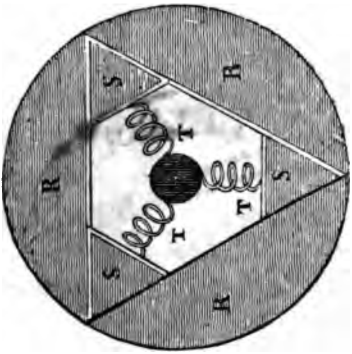
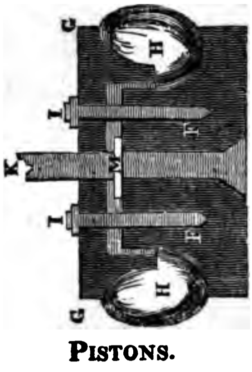


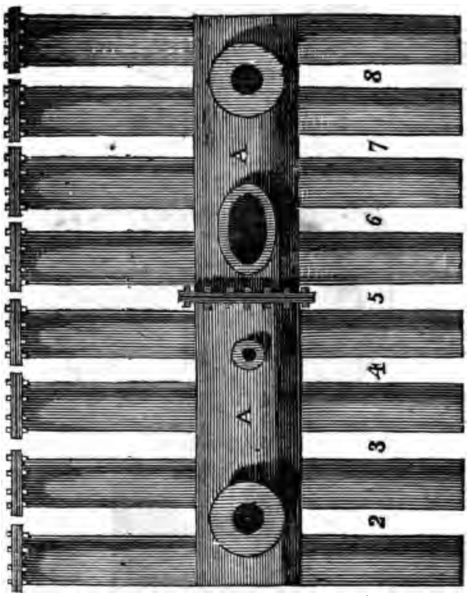
Fig. 9.



PISTONS.

Page 32

Fig. 13.



WOOLF'S BOILER.